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589.

(Vol. XXVIII.—April, 1893.)

THE OLD-TIME WATER-WHEELS OF AMERICA.

By JOSEPH P. FRIZELL, M. Am. Soc. C. E.

READ APRIL 19TH, 1893.

WITH DISCUSSION.*

In no way is the progress in any branch of art or industry more strikingly illustrated than by a glance at the methods in use a century or more ago. The annals of the American Society of Civil Engineers are supposed to be a repository of American practice and American methods in engineering. The writer, therefore, deems it no unworthy task to collect for preservation therein such examples as he can of the motors and methods employed by our ancestors of the preceding century in availing themselves of the power of water.

Had the task been attempted earlier, it would have been done better. The old millwright was a busy, practical man. He had little leisure, inclination or ability for putting his knowledge on record in

* Additional discussions on this paper received before July 1st, 1893, will be published in a subsequent number.

an intelligible manner. He made little use of books in his vocation. He learned his trade as an apprentice. He imparted his knowledge to other apprentices by example and word of mouth. Of the crude results of his labors very few examples now survive.

The sources of information available to the writer are: (1) Such isolated examples as have come within his knowledge and recollection. (2) The drawings and sketches extant in old books, which are usually mere hints and indications, requiring to be carefully studied and pieced out in order to yield any intelligent notion of methods of construction. Of these the book of Oliver Evans exceeds all others in value. (3) Suits at law for the interpretation of old grants of water, in which he has been employed as expert, sometimes involving an inquiry into the methods and appliances in use at the date of the grant. From the testimony and traditional knowledge of old millwrights, and such meager records as are available, some knowledge can be obtained.

The writer is quite well aware that this is a very hasty and incomplete summary of the subject; in fact, little more than a beginning. It is expected, however, that every man who takes it upon himself to comment on this subject will contribute something of his own knowledge, and that, in this way, this paper will result in putting on record a much larger body of information than it contains.

Up to the beginning of the present century the chief and almost the only application of water-power was for grinding grain and sawing lumber. Occasionally a wheel was set up, to create a blast for a foundry, or for fulling cloth, or for carding wool, the spinning and weaving being carried on in the household.

A wooden water-wheel consists in general of five principal parts, the shaft, the arms, the shrouding, the soling and the floats. It is only in the latter element and in the mode of letting on the water that any distinction exists between the overshot, the undershot and the breast wheel. The shaft was an oak log 18 to 30 ins. in diameter, dressed to a square, circular or polygonal form, with iron bands and gudgeons. There were two methods in use of attaching the arms to the shaft. The method of Figs. 1 and 2, Plate XXXVI, was not so common in this country as that of Figs. 4 and 5, although much used in Europe. The shaft was squared at the place of application of the arms, or, if octagonal, was made square by the insertion of corner blocks. The arms were halved or locked together and set firmly upon the shaft

PLATE XXXVI.
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FRIZELL ON OLD-TIME WATER-WHEELS.

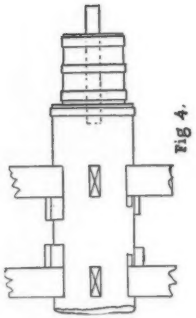

Fig. 4.

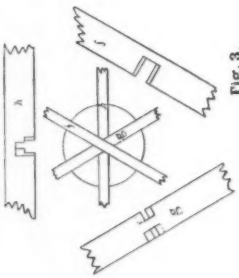

Fig. 3.

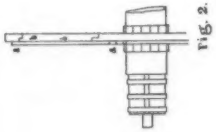

Fig. 2.

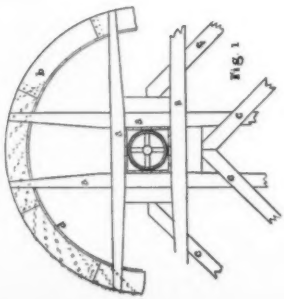

Fig. 1.

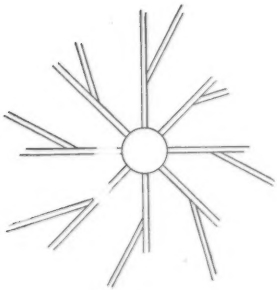

Fig. 5.

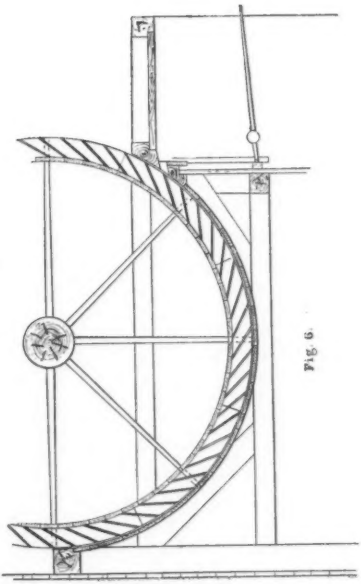

Fig. 6.

by means of wedges. This admitted of some adjustment of the wheel with reference to the shaft. This was a very strong and durable arrangement for wheels up to 14 ft. diameter. Beyond that size the four pieces forming the arms would not give sufficient support to the shrouding, and the additional pieces *c c c* were inserted, with the blocks on which they were footed. These were notched to the timbers *a a a* and fastened with pins or keys.

The second method of inserting the arms is indicated in Figs. 3 and 4. Though the shaft is here represented as round, it was more commonly dressed to a polygonal form—six or eight sides, rounded at the ends to receive the bands. The arms were inserted in mortises passing through the shaft. They were notched and locked together as shown at Fig. 3. This method required the length of the mortises to exceed the width of the arms by an amount sufficient to admit of their insertion. The widest vacancy thus made was closed by a heavy oak key solidly confining the arms as shown in Fig. 4. The drawing shows a wheel of six arms, each of the three pieces forming the arms being cut away to the extent of two-thirds of its width. The same construction is used for a wheel of eight arms, each of the four pieces being three-fourths cut away. When the number of arms exceeded eight, the additional arms were inserted as shown in Fig. 5.

All wheels run upon iron gudgeons inserted into the ends of the shafts. Figs. 1 and 2 show a cast-iron gudgeon. The part inserted in the wood is a cross of four feathers coinciding with the shaft in diameter. It is confined by heavy bands, driven on hot. A wrought-iron gudgeon is shown in Fig. 4. It is a little wider at the inner than at the outer end. It is inserted in a mortise cut from the outside of the shaft to a depth sufficient to bring the gudgeon to its proper position. After driving on the bands, the mortise is closed with keys and wedges driven with great force. The wood is further compressed by driving thin iron wedges into the end of the shaft.

The shrouding consists of segmental pieces *b* (Fig. 1) of 3 or 4-in. plank, forming a ring like the felloes of a wheel. They are attached to the arms in different ways. Halved and pinned as in Fig. 1, or forked as in Fig. 10, which shows a wheel with radial floats. With shrouding of sufficient thickness the arms are attached with mortise and tenon, which simplifies the insertion of the floats. The shrouding pieces are halved and pinned to one another at their ends, and where

the soling is wanting the joints are strengthened with splicing pieces.

The soling *d* (Fig. 1) consists of jointed planking fastened to the inner circumference of the shrouding, forming a tight circular drum and binding the whole wheel rigidly together.

The floats were sometimes inserted in grooves cut in the shrouding, sometimes merely "sprigged" to the shrouding and confined at their ends by blocks of 1-in. board, fitted in and nailed to the shrouding. In the earlier forms of breast and overshot wheels, they were inserted as shown in Fig. 6. They were different in the later forms, as will appear further on. The space contained between two consecutive floats was called a bucket.

Fig. 6 represents a high breast wheel and the manner of letting on the water. The part loaded with water is surrounded, at a distance of about ¾ in., by a tight drum of planking called the apron. This prevents the water from spilling freely out of the buckets as they descend. To transform this into an overshot wheel it would only be necessary to remove the apron, reverse the direction of the floats and carry the water over the summit. The overshot wheel did not usually have an apron, as that forces the water to leave the wheel in the same direction as it approaches. Both the overshot and breast wheel ran at a speed much in excess of what would be considered economical in modern practice.

Figs. 7, 8, 9 and 10, Plate XXXVII, show an undershot wheel in common use for grist mills. The floats being radial, the arms are forked on to the shrouding. The floats are set in dovetail grooves cut in the shrouding and confined with keys, the expectation being that they would yield instead of breaking when foreign matter was caught between the float and the sill of the race. The whole structure is evidently made light and elastic with that view. The floats moved with a velocity about two-thirds that due the head of water, instead of half, which is all that modern views of hydraulics would allow.

These wheels never required more than two sets of arms. They were never geared to more than two run of stones, and the width required was from 2 to 6 ft.

Figs. 8 and 9 show the style of gearing in use for two run of millstones; *a* is the "big face wheel" which gears with the two "wallowers" *b b*. On the same shaft with the wallower is the "little face wheel" *c*. This gears with the "trundle" *d*, which is attached to the

PLATE XXXVII.
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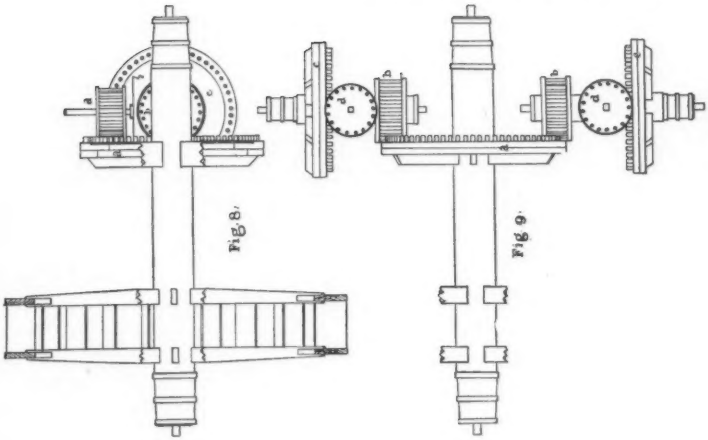

Fig. 8.

Fig. 9.

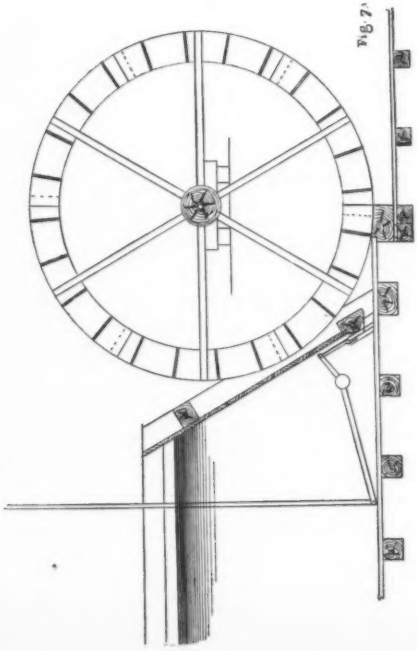

Fig. 7.

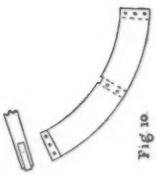

Fig. 10.

Fig. 12

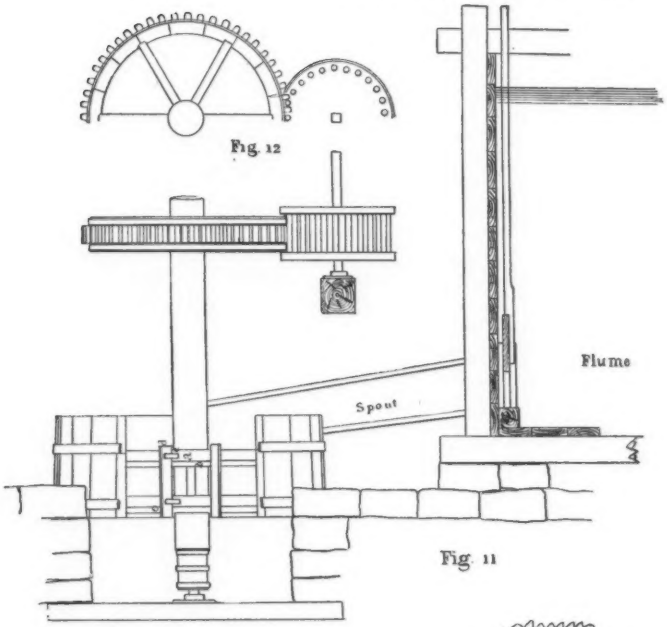

Fig. 11

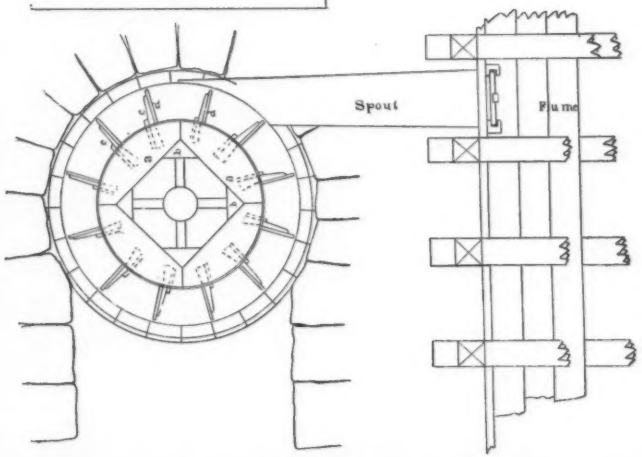

Fig 13.

PLATE XXXIX.
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FRIZELL ON OLD-TIME WATER-WHEELS.

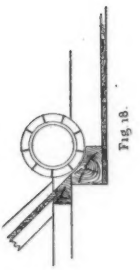

Fig. 18.

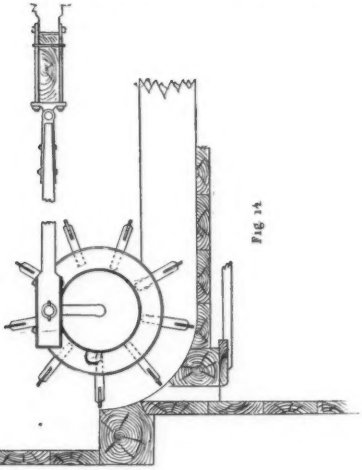

Fig. 14.

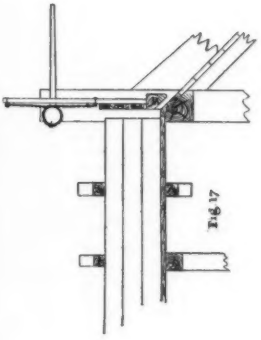

Fig. 17.

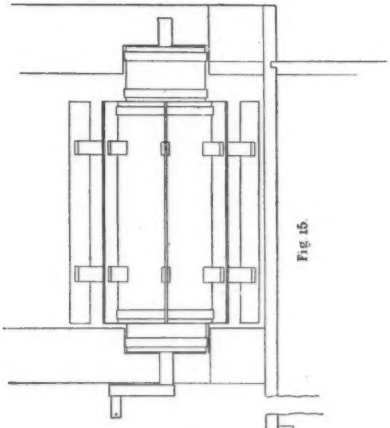

Fig. 15.

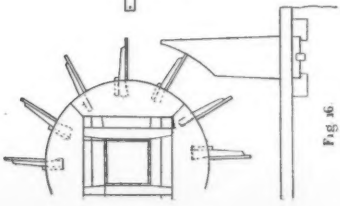

Fig. 16.

spindle of the millstone. The velocity of millstones was about 100 turns per minute for a 5-ft. stone, more for a smaller stone, less for a larger, a rough rule being to give the circumference of the stone a velocity of 1 500 ft. per minute. The gudgeon of the wallower shaft, next the main shaft, rested in a sliding block, which enabled the wallower to be drawn out of engagement with the big face gear, leaving one stone idle. It will surprise some readers to learn that the gudgeons of horizontal shafts ran on stone bearings. Oliver Evans gives directions for the selection of these stones: "hard and free from grit." He also enjoins great care, to prevent the heating of gudgeons, as it is liable to crack the stones on which they run.

This was the traditional gearing for a two-run mill. Mills, by this and closely analogous methods, were fitted up and operated for generations and centuries; and no man entertained a doubt that they embodied the perfection of mechanism.

Figs. 11, 12 and 13, Plate XXXVIII, show another wheel much used for grist mills, viz., the tub wheel, so called because it ran within a circular enclosure of thick planking put together in the form of a tub, without bottom. It runs upon a vertical shaft, and, with a head sufficient to give the necessary velocity, drives the stone without the intervention of gearing. More commonly a spur gear and trundle were used as shown. The wheel as shown is 7-ft. external diameter, with a head of 10 or 12 ft. The floats *d d* are radial and are fastened to starts *c c* inserted in the shrouding pieces *a a* by means of dovetail tenons and keys. The water was let on through a spout leading from the flume as shown.

A wheel of this construction was running at the Lowell machine shop some 30 years ago, and isolated specimens are still extant in old mills. Sometimes the circular rim was made lighter and attached to the floats forming a part of the wheel and revolving with it. Often the floats were set in an inclined position, more nearly perpendicular to the direction of the water issuing from the spout. Ordinarily a small wooden pipe was inserted in the top of the spout close to the flume, reaching to some height. The precaution was necessary, to prevent the collapsing of the spout on the sudden closing of the gate from the partial vacuum created by the momentum of the water.

A flutter wheel was simply a tub wheel without the rim, or perhaps more properly, a tub wheel without the tub. Plate XXXIX shows two

examples of this form of wheel as used in saw mills, which was their principal application. Figs. 14 and 15 show the wheel used for giving motion to the saw. This had to be of small diameter in order to give, under any ordinary head, the required speed of about 120 strokes per minute to the saw. The body of the wheel is represented as a solid piece of 27 ins. diameter. At one end a gudgeon is inserted, at the other a crank for giving a reciprocating motion to the saw frame, by means of a long wooden rod called the pitman. The floats are secured in forked starts set in to the body of the wheel by dovetail tenons and keys. The weight of the wheel was considered advantageous as giving a more equable motion to the saw. The water was let on from an opening at the bottom of the flume. Figs. 17 and 18 show another arrangement of sluice for applying the water, allowing it to fall down an inclined chute through a gate opening formed to give it the proper initial direction. Fig. 17 shows an old method of lifting and dropping a gate. The gate stem passed through a guide not shown. A chain for lifting the gate was attached at a point low down on the stem. Another for lowering it at a point near the top. The chains pass in opposite directions around a drum and are fastened at the back. The operation of the gate by means of the lever is obvious.

Fig. 16 shows the flutter wheel used in a saw mill for running back the carriage. It is 4½ ft. in diameter to the extremity of the floats. Its construction is the same as that of the tub wheel already described, except that the shaft is squared where the arms go on, and the latter are applied as shown at Fig. 1.

The figures of Plate XL show the mechanism of the primitive saw mill now as much an antiquity as the old domestic spinning wheel. *a* is the water wheel (Figs. 14, 15). *b* the flutter wheel (Fig. 16). The saw stretched in its frame *g*, ran in grooves in the fender posts *f f*. These were attached by hook tenons to the beams of the mill and were adjustable laterally by wedges. *d d* is the carriage which supports the log. It runs upon the ways *e e*, consisting of narrow plank set edgewise in notches cut in the floor beams and secured by wedges. The carriage is moved by a trundle on the same shaft with the rag wheel *c*. This wheel has an iron ratchet ring in its periphery, and is provided with teeth in the manner of a face wheel. The vertical shaft of the flutter wheel *b* carries at its upper end a lantern which remains in gear with the face wheel *c*, the flutter wheel conforming to the movements of the

PLATE XL.
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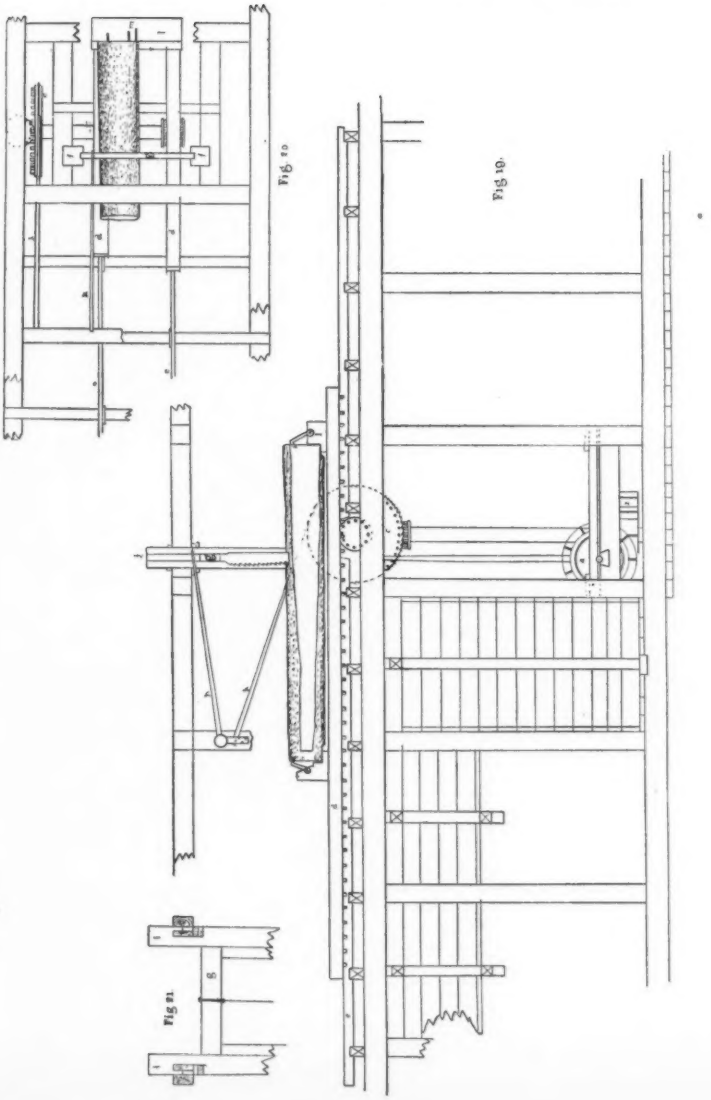
FRIZELL ON OLD-TIME WATER-WHEELS.



BREAST WHEEL of Later Construction.

18 or 20 ft. Head

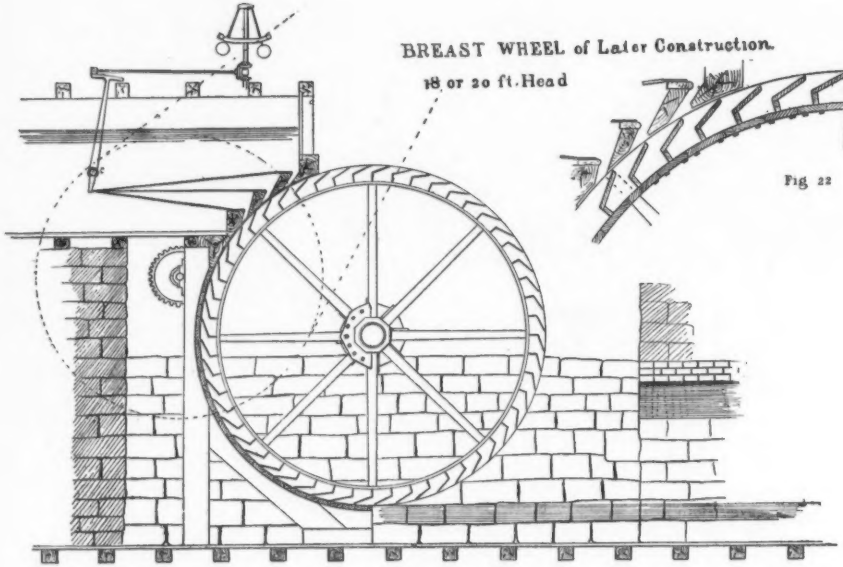


Fig. 23

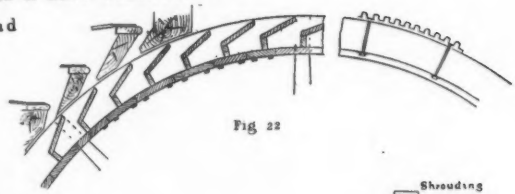


Fig. 22

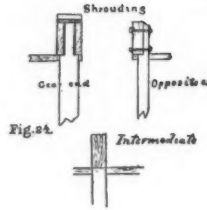


Fig. 24.

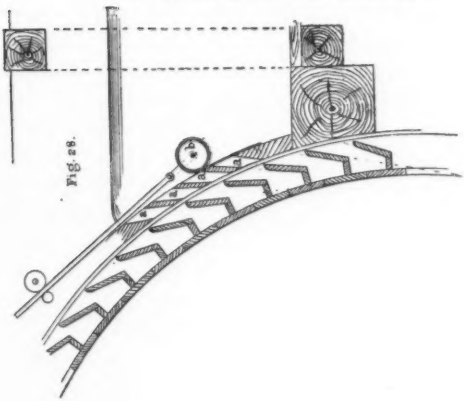


Fig. 28.

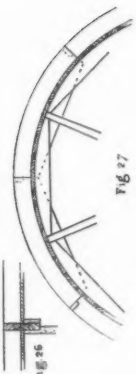


Fig. 27

Fig. 26

Breast Wheel of Later Construction
Longitudinal Section

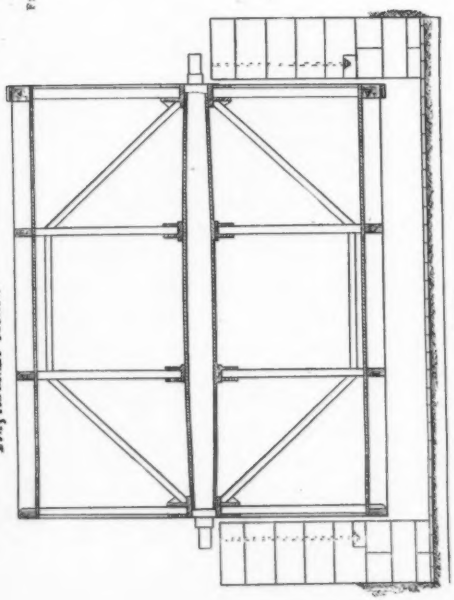


Fig. 25.

carriage. A series of teeth is inserted in the bottom of one of the side timbers of the carriage frame. They are alternately on opposite sides of the way on which it runs and fit the latter closely. The way is interrupted at the point where the trundle engages with these teeth. A lever h, worked by the top of the saw frame g, imparts a rocking-movement to a shaft with a projecting arm to which the hand pole k is jointed. This pole carries an iron "hand" at its opposite end resting on the rag wheel c. This wheel is provided with a pawl which prevents it from going backward, and, by the action of the hand pole and through the trundle, advances the carriage slightly at each stroke of the saw. The hand pole k is attached to the arm by a pin, and by means of a series of holes in the arm the feed can be varied according to necessity. One end of the log rests upon the head block l fixed upon the carriage, the other on the tail block which is adjustable to suit the length of the log. "Dogs," attached to the blocks, are driven into the log to hold it in position. When the tail block closely approaches the saw, a projection on the carriage strikes a trigger which lifts the hand pole and pawl off the rag wheel, turns a light stream of water on to the flutter wheel and the carriage runs gently back till the saw, which does not stop, enters the recess m in the head block. The attendant then releases the dogs, adjusts the log with his mill bar to a new position, drives in the dogs, drops the hand pole, and the work goes on.

The several figures of Plates XLI and XLII show the form which the breast wheel assumed early in the present century when textile manufactures began to extend. It was at a later date that iron shafts were introduced. In this form many specimens still survive, though no new ones are constructed. It was not far from 1845 that the breast wheel in New England began to be replaced by turbines, and as the substitution is not yet complete, it is apparent that the wheel must possess merit in order to hold its ground so long.

In this form the wheel has a width, or as we should say, length, greatly exceeding the old grist mill wheels, the one shown being something over 20 ft. long. It has four sets of arms and shrouding. The shrouding at one end is made much heavier than the others, and on this is bolted a series of segments forming a toothed ring through which the power is transmitted to a pinion called the jack gear. The arms radiate from cast-iron hubs or discs fixed upon the shaft. In the example shown, the larger ends of the arms enter recesses in the hub and are

strongly secured by hard wood wedges, then covered by a plate united to the disc by bolts and nuts. In the example of Plate XLI, the soling is secured to the shrouding by wood screws or lag screws. The buckets differ from the older form of wheel in being made in two parts—the start, which is radial to the wheel, and the float, which is usually in a direction nearly tangent to the soling. This bucket does not empty so soon as the older form. In the construction of Fig. 22 the floats and starts can be inserted in grooves cut in the shrouding, the soling being applied afterwards. In that of Figs. 26 and 27 the soling is put in first, forming a continuous drum or barrel before inserting the buckets.

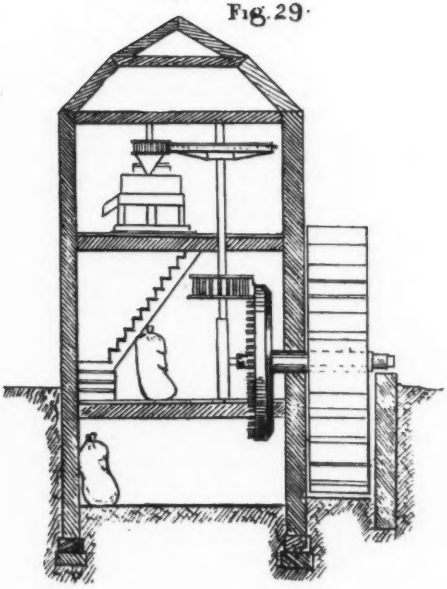
The admission of water is controlled by horizontal sliding gates, as shown, the wheel having three sets of three gates each. Each gate is attached by two rods to arms on the rocking shaft *c*, which is controlled by a regulator in the manner indicated. In wheels of more recent construction, the method of admitting the water shown at Fig. 28 has been employed. A heavy web of rubber cloth or leather is wound upon the iron cylinder *b*, which is rolled up and down under control of the regulator, covering and uncovering the orifices *a a a* according to the requirements of the work. This method, however, does not appear to offer any advantage over the old arrangement of sliding gates. On the contrary, the latter appears to offer a more ready adjustment of the velocity to sudden variations of power.

Ancient Gearing.—Large face wheels were made of two thicknesses of 4-in. plank, each wheel requiring 12 pieces called "cants." The pieces were all circled to the proper radius. Six of them were scribed, halved and pinned together into a continuous ring; the remaining six were butted together, forming another ring, which was confined to the former by a great number of wooden trenails. A face, some 6 ins. wide and projecting ½ in., was formed on this latter ring, in which the teeth were inserted. A set of arms was inserted in the shaft as already described for water-wheels. To these the wheel was adjusted by suitable notches and shoulders and secured by pins.

The lantern was formed of two discs united by the rounds which served as teeth. Each disc was made of two thicknesses of plank or boards pinned together and strongly banded. These wheels were attached to their shafts or spindles by wedges.

The Construction of the Spur Gear.—Figs. 11 and 12 are gathered from

Fig. 29.



descriptions of old gearing. A series of thick wooden staves or segments is bound together by iron hoops at the ends, leaving the central part free for the mortises in which the teeth are inserted. The segments are cut with the grain parallel to the axis of the wheel. The wheel thus formed is mounted on the arms in the manner indicated. A mode of constructing large spur wheels more common in Europe was the following: two sets of arms were mounted upon a square shaft in the manner shown at Fig. 1. To these were applied shrouding pieces, as in the case of the water-wheel, forming two rims at a suitable distance apart. Between these rims was inserted a series of segmental blocks, the grain radial, a tooth being formed on the outer end of each block. The whole was firmly bound together with bolts and straps.

Fig. 29, Plate XLIII, though not comprehended in the title of this paper, will be of interest in this connection. It is borrowed from Fairbairn's "Useful Information for Engineers," and represents a corn mill erected in England in 1730. It is said by Mr. Fairbairn to correctly represent the state of art with reference to mill gearing at that time. It shows that our American millwrights were not much behind their fellow craftsmen of England at that early date.

DISCUSSION.

F. Collingwood, M. Am. Soc. C. E.—I would like to ask Mr. Frizell whether he has paid any attention to cast-iron wheels? As a lad, I remember there was a foundry near where I lived where a great many cast-iron wheels were made. That was in 1845.

J. P. Frizell, M. Am. Soc. C. E.—Do you refer to breast wheels or overshot wheels of cast iron?

Mr. Collingwood.—They were small wheels, not over 4 ft. in diameter, with curved buckets cast in iron.

Mr. Frizell.—Many turbines have been and still are made almost wholly of cast iron. Some very efficient wheels are made in this manner. A preferable method, in my opinion, is, to make the floats and guides of wrought iron or steel. These are set up in the molds before casting, and on pouring in the molten metal they become solidly united with the cast-iron parts.

Mr. Collingwood.—I asked the question because it seemed to me that was probably the beginning of the introduction of the turbine, which has finally displaced the wheels that are described in this paper.

Mr. FRIZELL.—Water-wheels wholly of cast iron are not now, and never have been, to my knowledge, made. I use the term "water-wheel," now, in distinction from "turbine," to indicate a wheel running on a horizontal shaft, with a diameter nearly or quite equal to the fall, sometimes greatly exceeding the latter, the water acting on the wheel mainly by gravity. Such wheels continued to be made after the substitution of iron for wood in construction. The shaft, and what we might call the "hubs," that is, the members which unite the radial arms with the shaft, called rosettes or centers, were of cast iron; the remaining parts of wrought iron or wood. Wheels of this construction still continue to be made in Europe. As late as 1886, an elaborate German work, by Bach, was issued, devoted mainly to these wheels.

One of the largest and most elaborate wheels of this class, made wholly of iron, was erected at Greenock, in Scotland, some time previous to 1850. It was some 70 ft. in height. Its construction was similar to that of the Columbia bicycle, the weight of the water acting directly on the gears and producing no torsional strain on the shaft. For aught I know, it may be still in operation.

The extension of the iron industry, and the substitution of iron for timber, was not, as has been suggested, the sole cause of the replacing of these wheels by turbines. Other reasons contribute largely to this result. These wheels were bulky and occupied valuable space. In our rigorous northern climate they had to be housed in to protect them from the frost. I imagine that a turbine 5 ft. in diameter would furnish as much power as the enormous breast wheel that I have just referred to. There was still another reason of great force. These wheels revolved with a slow speed. The Greenock wheel referred to would not probably make more than two revolutions per minute, and an ordinary 20-ft. breast wheel not more than seven or eight. To bring this speed up to the requirements of modern industry involved changes and transformations consuming much power. So that, although the old overshot and breast wheel might, and no doubt often did, realize quite as large a percentage of the power of the water as the modern turbine, the losses incident to the intermediate gearing made the net result materially less. When we reflect that, as compared with the great wheel at Greenock, a modern turbine of 5 ft. diameter, would not only furnish the same power, but would run with a speed of 200 or 300 revolutions a minute, we perceive the enormous practical disadvantage under which the great wheel works.

For operations requiring a very slow movement, there is no question that water-wheels may be made to use water with an efficiency quite equal to that of the turbine, or even greater. The Sagebein wheel, invented in Europe, some 20 years ago, yielded by actual test, and under the hands of an experimenter no less distinguished than M. Tresca, an efficiency of 93%, a result never equaled or closely

approached by any turbine. This wheel had a diameter many times the fall, and revolved with a very low velocity, not more than 4 ft. per second at the circumference—thus wholly unsuited to most modern requirements.

There is one use to which a wheel of this kind may be applied in which it will probably never be superseded by the turbine, viz., the raising of water for irrigation or other purposes. A wheel of large diameter working on a very low head, too low to be available for a turbine, is provided with a series of small vessels, which fill when at the lowest point and at the summit of the wheel, discharge into a spout leading to the irrigation ditches. Many such wheels are met with in Southern Texas, Mexico and California. They are found in great numbers in India, China, Southern Italy and in Spain. Being used exclusively in hot countries, they require no protection from the frost. It is said that more water is raised by this means than by any other device known to man.

T. C. CLARKE, M. Am. Soc. C. E.—I remember seeing the old-fashioned wheels. It may be of interest to call the attention of the Society to the reason, which I do not see given in this paper, why all these wheels have gone out of date and have been superseded by the turbine. It is because the age of iron has superseded the age of wood. In the old days they made what they could in wood; the facilities of the country in working in iron were not sufficient to make the modern turbine, even if it had been invented. After the invention of modern machinery the wooden wheels were superseded by iron, just as you have seen the iron plows take the place of wooden plows on the farm.

Mr. FRIZELL.—I think the reason why these great wheels have been superseded is not altogether on account of materials, etc.

Mr. CLARKE.—That confirms the view which I suggested. It would be impossible to make a turbine or Pelton wheel out of wood; you have got to learn how to work the iron before you can make these modern wheels at all.

JOSEPH T. DODGE, M. Am. Soc. C. E.—This being the first time I have happened to attend a meeting here I feel a certain embarrassment about making any remarks, but I remember the use of a wheel with cast-iron curved buckets placed inside of a rim, which was used specially to run the carriage back where they were sawing lumber. The spout conveyed water down at an angle of about 45°, striking the curved buckets at a right angle as nearly as possible. Those curved buckets were supported by an outer and an inner rim. The overshot and undershot wheels were also in use, as has been described. That, of course, refers to the time between 1830 and 1840. I recall how the wheel was propelled in one saw mill. The saw was an up-and-down one; the wheel consisted of two rims with straight floats between; the water was delivered at an angle of 45°, striking the flat faces and work-

ing the crank which operated the saw. That is the way the country saw mills were operated. The overshot was used too, in some cases.

O. F. NICHOLS, M. Am. Soc. C. E.—The Burden over-shot wheel at Troy, which has, I think, been mentioned, should rank among the old American wheels. It was constructed of metal, and its diameter was very great, about 60 ft. The conditions under which it was used are still maintained, and the wheel is now in use. These conditions were very peculiar. There was a comparatively slight flow of water reaching the site of the wheel through the tail race, and falling 60 ft. over the wheel. This was an uncertain flow, reliable when you could have it, but you could not always have it, and at very low stages of the river every drop of the water was allowed to pass over the wheel. The wheel was 22 ft. wide on the face. It had 36 buckets, each 6 ft. deep, and, of course, every time it turned around there was a great deal of work done with a relatively small amount of water.

Mr. Frizell has spoken about the necessity of housing in; as to the space occupied by this Troy wheel, the wheel was placed in a niche or cranny of the rock that could hardly be used for any other purpose. They simply housed in a corner in the rock in which this wheel was placed. I doubt if the space could have been as well utilized in any other way. Working under a continuous supply of water, the efficiency of this wheel would be very great indeed, perhaps surpassing that of some of the modern turbines. The Burden Iron Company advise me that the wheel was built in 1851, is still in operation and is rated at 200 H. P.

The turbine wheels of modern times are among the most efficient of prime movers, and skill and ingenuity have so developed and improved these machines that they have been introduced to the exclusion almost of all the other forms which utilize peculiar surroundings, as at Troy. The modern wheel is compact and convenient; you can use several smaller wheels in the same space occupied by one large one.

I recall an instance in ordinary railway experience where it was desirable to furnish the power for drills, etc., in tunnel boring, and where it would have been very difficult to obtain or set up steam apparatus or indeed any machinery, and very expensive to transport it to the tunnel sites. In one or two instances we arranged to use a large overshot wheel. The reason for selecting this character of wheel was that, having a pretty good grade in the river, a mountain torrent, we could use a closed tube under very light pressure, carried at very light grade, about one-half of one per cent. This was enough to carry the water along the bank of the river, and then we simply extended this pipe or tube until we had reached the level of the top of the wheel. The wheel was made in sections and could be moved easily from one place to another and had no expensive foundations. A tur-

bine wheel in such cases would be out of the question. I wish Mr. Frizell had given us some instances and illustrations of the more celebrated of the older wheels. I know that the wheels he speaks of in Europe have been illustrated, and I wish the Troy wheel might have been pictured, and its efficiency, present condition and relative usefulness made known ; it was certainly one of the older of the powerful American wheels, and the forerunner of the more compact but not more efficient turbine.

Mr. LeValle.—I hope I do not impose on the kindness of the members. In France, especially on the Seine, where the current is very rapid, they have large wheels made like those of a steamboat; these are in the front. The paddles are very long and instead of moving the boat, the boat is anchored and the wheel is let loose and it is moved simply by the velocity of the current, and this is utilized for small industries, for turning a lathe, or for grinding coffee, or probably chicory or whatever goes into the coffee. I do not know whether these have come to the knowledge of Mr. Frizell. I think it would be interesting to know. I think they would be of value to small industries. I do not suppose they could be applied in this country to large industries.

Mr. Collingwood.—In reference to those wheels, I saw a great many of them in going down the Danube; there were quantities of those wheels. I think they were used for all milling purposes, I think for grinding corn.

A. McC. Parker, M. Am. Soc. C. E.—I have seen a water-wheel much of that pattern used in Colorado for irrigating purposes. A wheel was put in a stream so it could turn, and as it turned it had boxes on the outside of it, each of which took up a small amount of water which was thrown into a flume and used for irrigating purposes.

L. L. Tribus, Assoc. M. Am. Soc. C. E.—I remember an instance of what might be called an automatic water wheel running a small saw-mill which I came across in a small stream high up in a Swiss mountain district. I was curious, also wanting to rest, so went into the saw mill, but could find no one operating it. There was, however, a vertical saw industriously cutting through a log. I waited a little while to see what would happen. Attached to the end of the log was a small stick nailed at right angles to it; when the saw reached this end, the stick of wood struck a lever, releasing a gate in the flume; the gate fell and the mill stopped. When the proprietor returned from his morning's farming he would turn over the log, lift the gate and the mill would start in again and work until another board was sawed off. Two boards a day or perhaps three.

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(Vol. XXVIII.—April, 1893.)

NOTES ON COST OF OPERATING CABLE RAILWAYS.*

By D. BONTECOU, M. Am. Soc. C. E.

READ APRIL 19TH, 1893.

The demand in recent years for improved street railway service has developed an active interest in the cost and efficiency of cable roads, but the contributions to the general fund of knowledge by those who have built or operated them have not been in proportion to the importance of the subject.

There has been so much misinformation about the net results which can be expected from a cable railway, inspired by commercial interests, or by a vicious tendency to generalize without studying the special cases, that it seems proper to present a few facts, and to draw from them some inferences as to the real importance of what have been

* Discussions on this paper received before July 1st, 1893, will be published in a subsequent number.

properly considered as serious objections to the cable system. It is, perhaps, generally understood that the cost of operation for a fast and frequent service is less with the cable than with any other form of traction; and that the cost of first-rate construction is so large that a considerable volume of business is necessary to produce a return on the investment.

It is not well understood where to draw the line which determines the amount of gross receipts which will justify constructing a cable road of a given cost, and some conclusions may be drawn from an exhibit of the actual facts as to first cost and cost of operation in the case of a single system in Kansas City, which, as operated under the conditions of its last fiscal year, may be selected as representing the inferior limit of justifiable cable operation, its net earnings having been about 3½% on its cost; and the daily average of passengers transported having been but 1 706 per mile of double track. This system is well equipped and managed, has given a very satisfactory service, and affords an excellent illustration of what can be done with cable traction under adverse conditions of business.

The property comprises 8.54 miles of double track, disposed as a trunk line in the business part of the city, with three diverging feeders, the whole being operated as three distinct lines with one common terminus, and serving a territory of which about two-thirds is sparsely built up.

There are three ropes, 14 200, 29 500 and 31 000 ft. long, respectively, driven from a power-house at the junction of two of the lines, and a fourth rope, 18 900 ft. long, driven from a separate power-house at the outer end of the third line.

The speeds are as follows: 7.8, 9.85, 9.85 and 10.25 miles per hour.

The track includes 716° of double track curvature, with no grades exceeding 10%. The conduit is 36 ins. deep, and the rope 1¼ ins. in diameter, carried on 12-in. pulleys.

The cars are of the combination type, seating 40 persons, and running on two four-wheel trucks, with 22-in. wheels, and equipped with side-bearing grips. The machinery plant of main house consists of one 36 x 48-in., and one 32 x 48-in. simple non-condensing engine, which are run alternately, three 200-H. P. boilers, and an electric light plant. The driving drums are 12 and 14 ft. in diameter, with solid grooves, and one drum of each pair is an idler.

The machinery plant in the branch power-house consists of one 24 x 48-in. simple engine, with two 175-H. P. water-tube boilers and driving machinery. The main engine-house contains the offices and shop. The branch engine-house includes car storage for the cars of its own line, and there are car-houses at the ends of the other two lines.

The equipment comprises 99 combination cars.

The system has been in operation four years, so that its maintenance expense has reached a normal rate.

The construction account is as follows:

Real estate	$116 736 38
Underground obstructions	20 285 38
Substructure	542 819 65
Track and line machinery	276 074 99
Paving	159 091 83
Buildings	184 391 69
Machinery	130 003 37
Equipment	202 926 47
Ropes and splicing tools	30 759 65
Patents	12 950 75
Engineering, legal and miscellaneous	83 017 47
Discount and interest	146 931 31
Total	$1 905 989 11

The figures are exclusive of cost of franchise and grading new streets, and show an average cost per mile of $223 184.

The conditions and results of the operation of this line for the year ending April 1st, 1892, are condensed in the following table which is taken from the Company's published reports, the details of motive-power expense being somewhat amplified.

As the cars weigh 11 000 lbs., seat 40 people, and entail the same train-service expense as the more usual train of grip and trail car, each car mile is equivalent to two standard car miles, and the term car mile should be understood in what follows to mean a standard car mile.

OPERATING EXPENSES.

Car service and expense			$73 314 87
Injuries to persons and property			5 086 57
Secret service			528 65
Repairs, cars			4 862 14
Car-house service and expense			9 620 34
Maintenance, track and building			8 429 07
Motive Power—			
Fuel	$17 407 00		
Water	1 157 10		
Oil and grease	1 040 61		
Engine-house service	7 786 11		
Repairs, machinery	268 21		
Engine-house expense	299 01		
		$27 958 04	
Ropes	$29 380 60		
Rope service and expense	3 065 69		
Repairs of grips	1 789 46		
		34 235 75	
			62 193 79
Taxes			4 596 00
General and miscellaneous			26 610 30
Total			$195 241 73

The total car mileage was ("comb." cars, 1 415 366)	2 830 732
The number of revenue passengers carried	5 318 410
The number of passengers per car mile	1.9
The average number of (combination) cars run daily	61

This statement includes every item of expense, and shows a net result of 6.9 cents per car mile, or 10.3 cents if the interest on cost at 5% be considered.

While there is no unit of operating expense which can be used as a basis of comparison between roads run under different conditions, the "car mile" most nearly serves the purpose. The item of motive power being directly affected, however, by the ratio of weight of passengers to weight of cars. It is probable that the cost of operating these

lines might have been increased to a small extent, possibly ½% per car mile, by a larger volume of business.

Recurring to the details of motive-power expense, the fuel and rope accounts are objects of special interest. The fuel used is bituminous Kansas coal, with about 18% ash used in the form of nut and slack coal, in proportions of 3 to 2, the cost being $2.01½ per ton of 2 000 lbs. Allowing 30 H. P., or a consumption of about 255 tons per annum, for electric light and shop engine, we find that the coal consumption without deduction for getting up steam and banking fires was 5.93 lbs. per car mile, and about 2.1 lbs. of coal per ton mile. The great variation of engine loads makes it rather impracticable to determine the average power required; but by assuming the evaporation ratio as 7 to 1, as determined by tests made of one of the boilers run under average conditions and steam consumption of 28 lbs. per hourly horse-power, and allowing about 5% of the fuel for banking fires and getting up steam, an average horse-power of 575 is indicated, as developed by the two engines, this result seeming very reasonable in the light of the indicator cards which have been taken.

The total indicated engine friction is 64 H. P., and the total resistance of all ropes when no cars are on the line has been accurately determined at 345 H. P., leaving 166 H. P. as the average increased resistance of rope due to loads, and the traction of 61 cars with their passengers, or 2.72 H. P. per standard car. The actual efficiency cannot well be determined in the absence of reliable data of power required by the cars, and of the increase in rope resistance due to loads, but the net result of $\frac{9.9}{100}$ cents per car mile for all engine and fuel expense is sufficiently definite.

These figures by no means represent the results which may be attained by cable traction under more favorable conditions, and a better showing can probably be made by a number of roads. One line in the East had a record last year of 2.28 lbs. of coal per car mile, the average load being $4\frac{2}{3}$ passengers per car mile.

The cost of ropes on the Kansas City road, with incidental service and grip repairs, is 1.21 cents per car mile. These ropes last from six months, in the case of the short main-line rope, to two years in that of the independent branch-line rope, and have an approximate life, respectively, of 20 000, 55 000, 68 000 and 130 000 miles.

As the cables are bought on a guarantee and the cost charged out

each month, this account is a perfectly definite one, and its relative amount—about one-sixth of the whole—does not justify the terrors with which the maintenance of the ropes has sometimes been invested.

The statement of first cost given above is of value in showing the distribution of the construction expenses in a substantially built road, and in a general way the cost of the items which are peculiar to the cable system, and also as an approximate indication of the addition to the operating cost to be made on account of the interest charge. Nearly all these items would be modified by different conditions, but these lines could be built to-day for less money than they cost five years ago.

For further illustration, and for comparison with the cost of the Kansas City road, a summary is given below of the cost of a line in the East, built to serve a heavy traffic, and designed to secure results of permanence and small operating expense, which have been fully realized. It is almost straight in its alignment, very fully equipped, and the 33 000-ft. rope is driven by compound condensing engines of 300 H. P.

COST OF CABLE ROAD 3.05 MILES LONG.

Real estate	$67 065 21
Underground obstructions	46 500 00
Substructure and track	222 386 38
Paving	83 000 00
Power-house and vault	103 032 02
Machinery and plant	65 563 34
Equipment (88 cars)	85 949 98
Rope	10 394 34
Patents	8 000 00
Interest	22 136 05
Engineering, legal and miscellaneous	16 845 61
Total	$730 872 93

A total cost per mile of $239 240.

Census Bulletin No. 55 states the cost of 10 cable railways, varying from $160 000 to $684 000 per mile, and averaging $350 000 per mile.

These statistics, although bearing the Government imprint, are misleading in failing to show how they are derived, and certainly give no indication of the legitimate cost of cable railway construction under any usual circumstances, and irrespective of the value of municipal franchises, and cost of absorbed horse railway properties. It is true that the actual construction account will vary with the conditions of location and alignment, the extent of the equipment, and other causes, but the more usual range of cost should be between the limits of $150 000 and $250 000 per mile.

These figures are significant so far as they bear on the question of probable net earnings, and indicate an addition to the operating expense per car mile of from 2½ to 4½ cents, under almost all conditions, with a service not materially less than 1 000 car miles per mile of double track daily. It is true that there are cable roads which have cost somewhat more to build and a great deal more to operate than those the writer has referred to, but to reach conclusions upon the system it is proper to consider only such as have been built without entanglement with construction companies, or incompetent engineering, and which have been run with a reasonable amount of skill and economy.

An analysis of the affairs of cable roads which have been skillfully designed to meet the conditions of city traffic, with a view to the results of a long investment, and which are being intelligently operated, will usually develop figures of cost for doing the work so low that the popular statements as to expense of cables and extravagant use of power cannot well be sustained.

It is to be regretted that the interests of the owners of street railways usually require that their affairs should not be made a matter of public information, as otherwise facts of great interest and value could be readily collated bearing on the details of their operations. There has been sufficient experience, however, to take the consideration of cable roads as business propositions out of the region of conjecture, and to enable the engineer to make a reasonably correct forecast of cost, traffic and operating expense.

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TUBERCULATION IN WATER PIPES—DISCUSSION ON PAPER No. 575.*

By CHARLES B. BRUSH, JOHN BOGART, WILLIAM BARCLAY PARSONS, H. W. BRINCKERHOFF, WILLIAM METCALF, WILLIAM R. HUTTON, L. L. TRIBUS, F. COLLINGWOOD, DESMOND FITZGERALD, CHARLES C. HOPKINS, MANSFIELD MERRIMAN, DEXTER BRACKETT, JOHN C. TRAUTWINE, Jr., C. W. SHERMAN and JAMES DUANE.

CHARLES B. BRUSH, M. Am. Soc. C. E.—Mr. President, the paper certainly has the merit of being concise and to the point. Mr. Duane has told us in few words what he has to say. The conclusion he has reached, that after 11 years of service, a water main properly coated with tar is free from tuberculation, coincides with my own experience. I have had occasion during the past year to make several examinations of such coated water mains, 24, 20 and 14 ins. in diameter, that have been in constant use, and I have found little or no indication of tuberculation on the inside of the main. I believe that the general experience will be, that in waters of the class corresponding to the Croton,

* "The Effect of Tuberculation on the Delivery of a 48-in. Water Main." By James Duane, M. Am. Soc. C. E. Vol. XXVIII, p. 27.

that this result will obtain. Consequently I do not think we need fear very much effects of tuberculation on properly coated mains, at any rate until after a much longer period than 10 years.

I remember another main that I have examined during the last year that has been in service about 20 years; that was also coated with tar in the usual way, and was free from tuberculation. The use of water pipe not coated with tar is now practically obsolete; I do not know of any case where it is being used, and certainly such use would not be wise.

It may be out of place, perhaps, to refer at this point to another matter which is suggested by this paper, and that is the fact that after the Aqueduct is brought down to a certain point in masonry, it is carried beyond that point in iron pipes. I think most of us have seen how this is done. There are half a dozen or more 48-in. pipes laid parallel to each other, and, for a considerable distance, the main supply of the city is carried through these pipes lying close to each other. The result of a break on one of those lines might lead to very serious results to the City of New York, and it has always been a surprise to me that those mains were not carried through different streets, so that a breakage in one might not lead to a breakage of the others alongside of it. I do not know, however, that that has anything to do with tuberculation.

The paper is very interesting in relation to the loss in carrying capacity of the pipe by reason of tuberculation. I am a little surprised at the large results that seem to have been reached by the author, in the reduction of the capacity of the pipe. I do not think the paper clearly indicates either the proportionate area of the pipe that was affected by tuberculation, nor how much tuberculation projected from the face of the pipe. The result was certainly larger than I should have expected. The statement that the leakage from these pipes was practically nothing indicates the fact that the author allowed nothing for leakage. I fear that the leakage from mains is very much greater than generally supposed. The theory that leakage from the main can be determined by the fact that no leakage appears on the surface of the ground, I have long since found fallacious. Very much the worst leakage that I have had the misfortune to be obliged to provide against never appeared on the surface of the ground at all. I have had a number of instances of

mains, where I felt sure that they were tight, as far as any visible evidence to the contrary could be determined, and yet I knew those mains leaked, and I knew it because I knew the amount of water that was delivered from them, and the amount of water that was put into them. The difference was very considerable. I have determined that in several ways. I have determined it by filling a long main and shutting the gates and then finding that the water receded in the main. I also found it by taking the sum total of all the meter readings from the main and the amount of water put into it, and the difference was always the wrong way. I should not be surprised at all to find that there was a considerable leakage in the main under discussion, and, if there was, it reduces the percentage of loss as stated by the author in his paper. I am bringing this up as part of the discussion, because, if water leaked from the main, that would account in part for the differences he finds in his results. In the old main the leakage was probably a great deal more than in the new one.

JOHN BOGART, M. Am. Soc. C. E.—Mr. President, in connection with what Mr. Brush has said as to the unexpected in leakage of water mains, I had the opportunity of observing an instance a number of years ago. It was in the water distribution of the Central Park of the City of New York, which is an entirely separate distribution from that of the general city water supply. At one part of the Park it was very plain that there was a lack of pressure and of delivery from the hydrants from what ought to have been the case had the pipe been in perfect condition. There was no indication of leakage at the surface of the ground, although the probability of surface indication in the Park was generally as great or greater than would be the case in city streets. The pipes were largely laid under the grass surfaces at the sides of the roads, and any leak would be apt to declare its existence by a settlement of the ground, even though the water might not appear at the surface. The matter was bothersome and troublesome, but I could not locate the point of failure. At about that time it became necessary in the improvement of the Park to cut through one of the main drives for the purpose of building a new footway arch. At this place the original construction had been, as we found, a filling of loose rock; and where the pipe passed over this filling we found the leak, with a stream running out of the water pipe perhaps ¼ in. in diameter.

The water went down through this loose rock filling and passed into the lower park lake, and that leak had existed nobody knows how many years.

That is one example which shows the possibility of the existence of leaks without indications on the surface of the ground, and with little probability of discovery except by uncovering the pipe or by tests of pressure or quantity delivered. That pipe was not a cast-iron main, but one of the pipes which had been originally laid in the construction of the Park, a wrought-iron pipe with cement coating inside and out. It may be of interest to say that the place where the water came through the inside lining of cement was some distance from the place where the water finally worked through the wrought-iron pipe, and that was some distance from the place where it finally got through the outside covering of cement.

I want to add a word to what Mr. Brush has said in commendation of the paper under discussion. It seems to me that the examination of this tuberculous deposit, and the description of it as given by Mr. Duane, is of great value to all of us, and we ought to be very glad to have this kind of practical paper, showing actual experience and observation in just such instances; we don't have enough of them.

William Barclay Parsons, M. Am. Soc. C. E.—This question of the loss of head through tuberculation or other roughness on the interior surface of pipes is an old one, but it is well, occasionally, to have our attention called to some of these old principles, especially by such a carefully worked-out, concrete example. The loss of flow is not due to the diminished diameter of the pipe, but to the eddies that are formed by the particles of water impinging against the projections, and thus being deflected into the main stream and disturbing the even direct flow of other particles at a considerable distance from the sides. This tendency to eddy is far greater than one would suppose, unless attention had been called to it by actual experience.

Some time since, I had occasion to construct a basin, with a varying cross-section, through which water was to flow with a minimum of impediment, and where eddying would be fatal to the purpose. I found that although dealing with a smooth surface, like new tin, that a very slight change in the curves forming the bottom and sides of the basin would make an extraordinary difference in the results.

At the present time, it may be said that no cast-iron pipe is laid

uncoated; but it does frequently happen that an engineer is called upon to deal with lines of old pipe, and then, unless he bears in mind the effect of tuberculation, he will be seriously disappointed in delivery. As a case in point, I was recently called in to extend a small water-works system, built a few years previous. The force main was a 3-in. wrought-iron pipe. I found that the frictional resistance, as shown by the pressure-gauge on the pump, was 41 lbs., while according to the formula for clean pipes, it should have been 14 lbs. The loss due to tuberculation was, therefore, 27 lbs., or nearly 200% of that due to ordinary condition. Wrought-iron pipe, however, rusts much faster than cast iron.

I had an opportunity, some few years ago, to examine a cast-iron main that had been laid something like 30 years, and the coating inside of it was apparently as perfect as any new pipe that I had ever seen. The coating was smooth, clean and unbroken, and that pipe had seen continuous service during that time.

H. W. Brinckerhoff, M. Am. Soc. C. E.—As an illustration of how large leaks may exist undiscovered in water pipes, I would mention that in putting in the tracks of the Broadway Cable Road on Seventh Avenue we had to remove a portion of what had been a water pipe, which was considerably tuberculated. It had been broken square across, apparently for a long time, as the edges were rusty, but no leak appeared on the surface. I do not remember what its diameter was. Do you remember, Mr. Carr? You can tell us more about it.

Albert Carr, Assoc. M. Am. Soc. C. E.—It was a 6-in. pipe. I don't know how long it had been down. The pipe was laid on a miserable rock filling, the cast-iron pipe right down on it; large pieces of rock had been dumped into the trench. We found some pipe broken square across, and apparently no leak; nobody had known anything about it. There was a 12-in. sewer trench filled with this same sort of filling, and the water had a good chance to get away.

William Metcalf, M. Am. Soc. C. E.—There may be some other members as ignorant on this subject as the Chair; would somebody who is well informed explain the cause of the tuberculation? Is it from the rusting of the pipes or from deposit of the water? Will Mr. Brush enlighten us?

Mr. Brush.—My impression is, from the deposit of the water; the rusting forms a nucleus, and then the deposit forms around it. My con-

clusion is that the failure of wrought-iron pipes is very much more rapid than that of cast iron, as has been stated by Mr. Parsons. That occurs more rapidly in ordinary black iron than in any other; for that reason it is not desirable to be used as a service pipe. The sediment in the water, as soon as the rust commences, begins to form around the rusty places, and it is surprising how soon a wrought-iron pipe will close entirely. In order to avoid that I have used galvanized iron, but the difficulty is that when it commences to go, it goes sooner than black iron; there seems to be a galvanic action, and the pipe seems to rust away very rapidly.

There was a process in use here a few years ago that was called the "Rustless Process." I have used that quite frequently, and, at first, with excellent results. I have laid the pipe along the top of banks of reservoirs, and there was no sign of rust at all. I did that for one season, but I found that in putting the pipe together, the grip of the pipe tongs injured the coating, and then the pipe commenced to rust. That was remedied by putting on a preparation that answered the purpose very nicely. I found, however, that after two or three years of use that pipe corroded on the inside just as badly as black iron did, and, therefore, what I thought was a very valuable preparation for the use of wrought iron, I have found since by experience to be not so valuable. I do not think there is any preparation, except the tar coating, that will prevent tuberculation. I do not suppose that will prevent it forever, but it does so to a greater degree than any other preparation we have. So far as the two pipes, wrought and cast iron, are concerned, the cast iron resists tuberculation better than wrought.

The protection of water mains from leakage is one of the questions we could talk a long time about. One of the most peculiar cases that has come under my observation was that of a main which had been laid about 20 years. Although the main was 12 ins. in diameter, the pressure was not very great. Suddenly there was a break, and the supply of the town was cut off. We shut the gates and found that a root from a tree had gradually enlarged until it forced the pipe up and broke it. The pipe was broken square across. In two or three instances, where leaks have taken place, it has taken our people a long time to find them. In crossing a culvert, if the pipe happens to be submerged or a little out of sight, the water can be running a long time before the

leak is discovered. In one case the leak was so great that we lost our pressure entirely, and it took us about ten hours before we could find our leak; and finally, when we found it, the water appeared fully 500 ft. from the pipe. The leak had taken place under the frozen crust and had got out into the stream and was not noticeable. It was a small river that was flowing there, and we did not know of it until a farmer came in and said his hencoop was being drowned out.

There was a case at a river crossing where we used the very best pipe that I knew of for that purpose, a ball-and-socket pipe which is known as the Ward joint, which accommodates itself to the inequalities of the bottom of the river. For a long tim e we knew there was a leak in the main, but could not find it. The water was 14 ft. in depth. There was no indication on the surface at all, but from our draft we knew we were losing easily about 1 000 000 galls. a day, until, all of a sudden, we lost everything. Then we found there had been a stream there that had scoured out the bottom of the river, and that the pipe had held together until iron met iron, and then the bell had snapped off and the whole thing separated. I knew for two months before that break took place that there was a leak, but I could not locate it until it located itself; and I am perfectly confident that a large portion of what we call "waste" is leakage from mains. By that I do not mean to discredit the consumers' waste at all, which is enormous; but there is a large portion of what we know as waste, the difference between the amount of water put in the pipes and the water we receive from our pipes, that gets out of the mains without our knowledge, and it is a problem to locate it; it usually locates itself.

William R. Hutton, M. Am. Soc. C. E.—Tubercles are formed almost entirely by chemical action, although in some of the European water pipes calcareous tubercles are found. They are not usually formed in hard waters. The effect of tubercles in diminishing the discharge is owing not so much to the reduction in the size of the pipe as to the resistance to flow caused by the roughening of the surface, and the percentage of loss will vary with the degree of roughness. Darcy's extensive experiments upon the pipes of Paris and Dijon led him to conclude that, in a general way, the loss is about 33 per cent.

Mr. Brush.—The reason I thought the percentage was high was because, after I had been running our mains for about one or two years, I found that I was not getting the amount of water that I ex-

pected to receive, and attributed it to tuberculation; I found that much of it was due to leakage from the mains.

Mr. HUTTON.—In open channels, the coefficient dependent upon roughness will vary from 130 down to 50.

L. L. TRIBUS, Assoc. Am. Soc. C. E.—I have had opportunity for observing this tuberculation during the recent removal of a wrought-iron stand pipe some 20 ft. in diameter by 80 ft. in height. It had been in constant use for about eight years under a very variable daily service, being for a few hours very full of water, and then rapidly lowered to within 15 ft. of the bottom. The quality of the water was, during the flood season in the river from which the supply was taken, very soft; during the summer and autumn, in the low-water stage, very hard. That portion of the stand pipe always full of water showed very few tubercles, and also that near the top, which was in contact for but a short time daily.

These tubercles in the intervening portion were, in appearance, as Mr. Duane has described, from ¼ to ¾ in. in diameter at their bases, from ¼ to ½ in. in height, and shaped like a hollow cone, or mud-wasp nest. A slight jar served to detach most of the tubercles, and exhibited a pitted condition of the iron underneath, clearly showing a chemical action rather than a sedimentary deposit from the water; further evidenced by the lesser number of tubercles in the lowest part of the stand pipe, where sedimentary matter was abundant.

Mr. BRUSH.—I think in every case where we find this tuberculation we will find pitting of the iron, just as Mr. Tribus stated. I think that invariably occurs. My theory was that rusting took place first and then tuberculation commences there afterwards.

Mr. BRINCKERHOFF.—I want to ask Mr. Brush if any chemical analyses of the tubercles have been made. What are they made of?

Mr. BRUSH.—I do not know of any, sir. I have found so little in my experience that I have not found it necessary to make the examination.

Mr. HUTTON.—There have been some made.

Mr. BRINCKERHOFF.—The difficulty that you speak of in Ward's patent joint has since been obviated, so that the pipe will hold together without breaking, even if there is no packing.

Referring to the so-called "rustless" iron, I heard of a case in which a pretty large piece of work was done with it in piping a private

residence, and it was found that it rusted very badly. The trouble seemed to be that the coating of black oxide was practically inelastic, and that the strains to which the pipes were subjected in shipping and handling cracked the oxide both inside and outside. The coating seems to be an excellent protection as long as it is intact; but it does not yield at all and the least bend destroys its integrity.

F. COLLINGWOOD, M. Am. Soc. C. E.—I would like to ask Mr. Brush whether it makes any difference as to the hardness of the cast iron—I think Mr. McAlpine once stated that the best iron for resisting salt water was the hard white iron—whether there would be any difference in the various kinds of cast iron in this case?

Mr. BRUSH.—I do not think it is desirable to use hard cast iron in water pipes. I would much prefer softer iron. A practical consideration, also, in the laying of the pipe requires the use of a soft iron. Where cutting is needed for making connections, a hard, brittle iron would be not only unsuitable, but unsafe to tamper with, while the softer grades will cut readily and truly.

Mr. METCALF, M. Am. Soc. C. E.—I would suggest, in considering the matter of the rustless iron, whether it would not be worth while for engineers to consider the effect of a long-continued red heat on the iron and the action of steam applied to it afterwards; whether it is not seriously injured in structure before it is put into use.

I would like to emphasize the remarks of Mr. Bogart in regard to this paper. There can be no question that practical, short papers of this kind are of the utmost value. I wish particularly to call the attention of the younger members to this: if you meet anything that you do not understand, write it out, and you will draw out the experience of the older members.

Mr. BOGART.—Mr. President, what you have said encourages me to say a few words more. That water pipe coated with the tar preparation is decidedly better than pipe that is not coated with it is a fact which, of course, engineers know pretty well; but sometimes it is necessary to persuade people who have to do with supplying the funds for these projects that such a pipe is best, and it is well to have a paper which shows that by actual experimental observation. With reference to the flow of water through these pipes, whether it may be of the exact percentage resulting from the observations of Mr. Duane, or whether the results ought to be modified somewhat by the possibility

of leakage, yet the comparison of the flow through the coated pipe and the uncoated pipe is of great value, and this paper may lead to more careful observations, if they are necessary, in just such instances, and the better determination of the additional complications which surround the subject.

DESMOND FITZGERALD, M. Am. Soc. C. E.—The subject of a proper lining for a cast-iron main is a most important one, when we consider the enormous mileage of cast-iron pipes in use for various purposes.

It is well known that as far as the water-supply question is concerned, there is a vast deal of difference in the action of different waters in producing tuberculation. Some waters have practically no effect on a cast-iron pipe, whether it be coated or uncoated.

The Boston water, which is very similar to the Croton, has a decided effect on a cast-iron pipe, although, happily, the tubercles, after a certain lapse of time, do not increase, as stated in the second proposition at the end of Mr. Duane's paper. The third and fourth propositions should, however, be received with caution, if not suspicion. Certainly such propositions cannot apply to the Boston water.

The writer has found tubercles in a tar-coated pipe at the end of one year after laying. Sometimes, after removing a tubercle which is just beginning to grow, the lining will be found to be intact underneath, as far as the eye can discern; probably some microscopical hole may exist.

If some one can bring forward a practical lining which will be proof against tuberculation, it will be worth a great deal of money to the water works of the City of Boston.

CHARLES C. HOPKINS, M. Am. Soc. C. E.—In 1891 the demand for water in the City of Rome, N. Y., made necessary the removal of the water-works force main from the pump house to the reservoir, and the relaying of a larger main. The old force main, 12 ins. in diameter, laid in 1892, extended westwardly from a valve placed within the pump house; this main was of wrought iron, with cement lining and exterior coating, except a short portion immediately west of the aforesaid valve, which was of cast iron, coated at the pipe foundry in the usual manner with hot tar. Just east of the valve, connecting it with the pumping machinery, was a special casting, made at a local foundry and without the hot-tar coating, and possibly with no coating at all. The writer was unable to learn from the firm making the special

casting, whether the latter was entirely uncoated or only painted, as was customary at their foundry.

The removal of these pipes, after 18 years' constant service, showed the coated pipe entirely free from incrustation or tuberculation of any kind, in fact, with the tar coating quite perfect, although probably not as perfect as when first applied; while the diameter of the special casting was reduced fully $\frac{3}{8}$ in. by the tubercles. The tubercles were approximately hemispherical and appeared to overlap each other.

The water for the city's supply is pumped from the Mohawk River, and at the pumping station is soft, having but 2.5 to 3.0 grains of carbonate of lime per gallon.

MANSFIELD MERRIMAN, M. Am. Soc. C. E.—The values of the coefficients for the second experiment, where the same water passed through both the tuberculated and clean mains, can be compared without knowing the quantity of water discharged. Let C_1 and C_2 be the respective coefficients, $I_1 = 0.00035$ and $I_2 = 0.00018$ as observed, A = area of cross-section and R = hydraulic radius. Then

$$Q = AC_1\sqrt{RI_1} = AC_2\sqrt{RI_2},$$

whence $C_1\sqrt{I_1} = C_2\sqrt{I_2}$, and accordingly $C_1 = 0.72\ C_2$, or $C_2 = 1.40\ C_1$ gives the ratio of two coefficients.

In the first experiment, the value $C = 96$ for the tuberculated mains, was deduced by using the discharge as checked by the flow through the Aqueduct at Sing Sing. In the second experiment there is no similar check, but the assumption $C_1 = 96$ for the old main brings out $C_2 = 134$ for the new one. The velocity of flow in the two experiments was not the same, however, and this might make a variation of several per cent. in C. In the first case the velocity was 2.1 ft. per second, in the second it was 1.65 ft. per second. According to the curves derived by Hamilton Smith, Jr., M. Am. Soc. C. E., in his thorough study of the subject, the coefficients for clean pipes corresponding to these velocities are 131 and 127 respectively instead of 134. If these be correct, the coefficient for the tuberculated pipe for velocity 1.65 ft. per second should be 91 instead of 96. Perhaps it may yet be possible to obtain the record of flow through the Aqueduct at Sing Sing on the date of the second experiment, and thus determine better values of C_1 and C_2.

The tuberculation in this case was sufficiently marked to produce

a reduction in cross-section and hydraulic radius, which alone would probably diminish the discharge nearly 2 per cent. The paper forcibly illustrates the marked influence of deterioration of surface in checking the flow, and the great value of interior coating in preventing tubercles.

DEXTER BRACKETT, M. Am. Soc. C. E.—All of the pipes laid in Boston from 1848 to 1868, with the exception of a few hundred feet, were uncoated, and the entire inner surface of these pipes is covered with tubercles from ¼ to 1 in. in thickness. As early as 1852, only four years after the completion of the works, the late Mr. E. S. Chesbrough, M. Am. Soc. C. E., then City Engineer, reported that "all the large pipes that have been examined have been partially or entirely covered on their inner surfaces, some with detached tubercles, varying from ½ to 2½ ins. base, with a depth or thickness in the middle of from ¼ to ¾ in., and some entirely to an average depth of ½ in., with a rough coating as if the bases of the tubercles had crowded together."

The experience in Boston confirms Mr. Duane's opinion that the growth of tubercles in an uncoated pipe is at first very rapid, but that the growth practically ceases after from 7 to 10 years.

In 1866 I made some experiments to determine the effect upon the discharging capacity of 4 and 6-in. pipes, of removing the growth of tubercles by means of a mechanical scraper. The pipes were cleaned in a manner similar to that described by E. H. Keating, M. Am. Soc. C. E., in a paper "On the Removal of Incrustation in Water Mains" (*Transactions*, April, 1882). The scrapers used were of different design from those used by Mr. Keating, but the method of operation was practically the same.

The discharge of the pipes both before and after cleaning was measured by means of a Deacon meter; the friction head was determined from readings of Bourdon gauges attached to the fire hydrants. Very great accuracy was not aimed at in these experiments, and they are given to show, in a general way, the great loss in discharging capacity caused by the coating of tubercles. The following tables show the results of the experiments.

Tuberculated pipe, 38 years old
Length, 525 ft.; original diameter, 6 ins.

Observed head. Feet per 1 000.	Velocity. Feet per second.	Observed discharge. Gallons per minute.	Value of c in formula $v = c\sqrt{RI}$	Calculated discharge of clean pipe under same head. Darcy's formula.
1.30	0.38	33.3	29.5	120
2.50	0.57	50.0	32.2	165
6.90	0.95	83.3	32.3	275
14.40	1.13	100.0	27.1	395
19.20	1.32	116.6	27.1	455
25.40	1.51	133.3	26.8	525
33.80	1.70	150.0	26.1	600

Same pipe, after cleaning.
Length, 525 ft.; original diameter, 6 ins.

Observed head. Feet per 1 000.	Velocity. Feet per second.	Observed discharge. Gallons per minute.	Value of c in formula $v = c\sqrt{RI}$	Calculated discharge of clean pipe under same head. Darcy's formula.
2.70	0.76	66.6	41.5	170
1.50	0.95	83.3	68.8	125
1.50	1.13	100.0	82.5	125
3.80	1.51	133.3	69.4	205
4.20	1.70	150.0	74.2	215
6 50	2.08	183.3	73.1	265
9.40	2.46	216.6	71.8	320

Tuberculated pipe, 38 years old.
Length, 720 ft.; original diameter, 6 ins.

Observed head. Feet per 1 000	Velocity. Feet per second.	Observed discharge. Gallons per minute.	Value of c in formula $v = c\sqrt{RI}$	Calculated discharge of clean pipe under same head. Darcy's formula.
1.00	0.38	33.3	34.0	100
3.50	0.57	50.0	27.3	195
4.70	0.76	66.6	31.4	225
5.40	0.95	83.3	36.3	245
9.60	1.13	100.0	32.6	325
11.80	1.32	116.6	34.5	360
14.70	1.51	133.3	35.4	400
18.00	1.70	150.0	35.5	440

Tuberculated pipe, 38 years old.
Length, 890 ft.; original diameter, 4 ins.

Observed head. Feet per 1 000.	Velocity. Feet per second.	Observed discharge. Gallons per minute.	Value of c in formula $v = c\sqrt{RI}$	Calculated discharge of clean pipe under same head. Darcy's formula.
22.9	0.47	18.3	10.7	175
33.5	0.81	31.7	15.3	211
36.1	1.06	41.7	19.3	218
50.1	1.23	48.3	19.1	258

Tuberculated pipe, 38 years old. Length, 629 ft.; original diameter, 4 ins.

Observed head. Feet per 1 000.	Velocity. Feet per second.	Observed discharge. Gallons per minute.	Value of c in formula $v = c\sqrt{RI}$	Calculated discharge of clean pipe under same head. Darcy's formula.
21.02	0.51	20.0	12.2	169
36.95	0.83	33.3	15.3	221
48.70	1.19	46.6	18 7	254

These experiments show, as might be expected, owing to the small size of the pipe, a much smaller value for C than was obtained by Mr. Duane.

It will be noticed that the discharge of the 6-in. tuberculated pipes was from 25 to 35% of the quantity which a clean coated pipe might be expected to deliver under the same head, and that the discharging capacity of the pipe was more than doubled by the removal of the tubercles. The 4-in. pipes show an even greater resistance to the flow, and a head of 25 ft. was required to deliver the same quantity of water that a clean pipe would furnish under 1-ft. head.

By means of the scrapers above mentioned the tubercles were removed from 58 000 ft. of 6-in. pipe at a cost of 14 cents per foot, and from 20 300 ft. of 12-in. pipe at a cost of 20.6 cents per foot. These prices include 5 cents per foot royalty paid for the right to use the scraper.

My observation of the coated pipes, in connection with the works in Boston and other cities in Massachusetts, leads me to question Mr. Duane's conclusion that "a properly applied tar coating is an absolute protection against tuberculation," if it is assumed that pipes ordinarily furnished by the manufacturers have the coating properly applied. Coated pipes in this vicinity, after from 10 to 15 years' use, are generally pitted to a greater or less extent with tubercles.

The first coated pipes used in Boston were of Scotch manufacture, and a few hundred feet were laid to determine the value of Dr. Angus Smith's coating. In 1866, after eight years' use, this pipe was reported "to be as free from rust as when first laid," but on a second examination, in 1873, it was found that tubercles had formed, "about half the size of an English walnut, and very evenly distributed, averaging about 20 to the foot."

My opinion is also confirmed by the results of some experiments made by Mr. F. F. Forbes, Superintendent of the Brookline Water Works, and reported in the *Journal* of the New England Water Works Association, Vol. 6, on the discharge of a 16-in. tar-coated main 13 350 ft. in length, which had been in use 18 years.

These experiments give values of C as follows:

Velocity. Feet per second.	Observed head. Feet per 1 000.	Value of c in formula. $V = C\sqrt{RI}$.
1.15	0.459	92.7
1.40	0.713	90.9
1.70	1.011	92.6
1.97	1.44	90.0

In order to afford complete protection against the growth of tubercles, the tar coating must be an absolutely perfect covering on the surface of the pipe, as every minute hole in the coating forms the nucleus about which a tubercle is sure to form, and it seems to me that more attention should be paid to the details of the composition of the tar coating and to the method of its application.

JOHN C. TRAUTWINE, Jr., Assoc. Am. Soc. C. E.—Mr. Duane's record of his experiments with tuberculated cast-iron pipes forms a valuable contribution to our store of facts. The values of the coefficient n of roughness in Kutter's formula, deduced from these results, are approximately: $n = 0.0112$ for the clean pipe and $n = 0.0154$ for the tuberculated pipes. The former value corresponds well with those usually obtained. The latter is rather low as compared with average values obtained from other experiments.

In Mr. Duane's paper there is one paragraph to which I am constrained to take exception. It is this:

"In common with many hydraulic engineers whose sympathies are rather with the practical than the theoretical, the writer has a decided preference for the simple formulas of flow of the Chezy type over the more complex, and he believes not more accurate, ones of Kutter, Weisbach *et al.;* for the degree of accuracy obtainable from any formula is dependent on the ability of the user to make a more or less (usually less) scientific guess at the value of a modifying coefficient appropriate to each specific case."

Considering how long Kutter's formula has been before the engineering profession, and how extensively it is to-day employed, it is surprising how tenaciously certain misconceptions prevail respecting it.

Four of these erroneous ideas find more or less direct expression within the narrow confines of this paragraph, and are as follows:

First.—That Kutter's formula is intended to cover the same ground as the Chezy formula, and appears as its competitor.

Second.—That Kutter's formula is based rather upon theory than upon practice.

Third.—That Kutter's formula fails to enable the user to make a scientific guess at the value of the modifying coefficient appropriate to each specific case.

Fourth.—(By implication only.) That the application of Kutter's formula is as cumbersome as its appearance would indicate.

Let us see to what extent these four articles of impeachment are based upon fact.

1st. So far from being in any sense a rival of the well-known Chezy formula, $V = C\sqrt{RI}$, the Kutter formula assumes the correctness of that expression and limits itself solely to the determination of the coefficient C.

2d. Kutter's formula for the value of the coefficient C in the Chezy formula is the result, not of abstract theorizing, but of a careful comparison of all available and reliable data. It is therefore purely empirical, and in the highest degree practical rather than theoretical.

3d. Kutter's formula is pre-eminently adapted to enable the user to make a guess, not only more scientific, but more probably correct, than is otherwise possible, at the value of a modifying coefficient appropriate to each specific case. It is, I think, quite safe to assert that if there is any one thing in the literature of hydraulics better calculated than another to aid such guessing, it is that monument to the intelligent and indefatigable thoroughness of Mr. Hering, the Table No. 1 of our translation of Kutter's work. This table, covering 90 pages, contains the results of "over 1 200 gaugings," comprising all that the most diligent search could bring to light, and ranging from small glass pipes 0.9 in. diameter up to a brick-work siphon 7.5 ft. diameter, and from 3-ft. semi-circular channels in neat cement to the Mississippi River. For each gauging this table gives, in addition to other data, the four values, V, C, R and I of the Chezy formula, together with Kutter's coefficient n of roughness.

4th. While Kutter's formula for the value of C in the Chezy formula is indeed very complicated, it must be borne in mind that in practical work its results are obtained, not by arithmetical computation from the formula itself, but by the use of the "Kutter diagram," which embodies that formula. Having made our guess at n from Table No. 1, and having, of course, from the data of the case the values of R and of I, the mere stretching of a cord between two points in the diagram gives us immediately the value of Chezy's coefficient C, as obtained by Kutter's formula. Indeed, by means of an addition to the diagram, suggested by Mr. Hering in *Transactions* American Society Civil Engineers, January, 1879, we may obtain from the diagram, by a second stretching in the cord, the velocity itself by Chezy's formula, with the

value of C determined by the light of the experiments upon which Kutter's formula is based.

In short, the Kutter formula, as embodied in the diagram by which it is invariably represented in practice, is nothing more or less than the means by which we are enabled to apply the Chezy formula with the utmost simplicity and with the highest degree of probable accuracy at present attainable.

C. W. SHERMAN, Jun. Am. Soc. C. E.—This is a paper of considerable interest and value to hydraulic engineers, especially as it shows the value of a good coating in preserving the pipes. I think, however, that the rapidity of tuberculation in uncoated pipes is not as surprising as it seemed to Mr. Duane. I find in the handbook of the Addyston Pipe and Steel Co., the following statement: "In Boston, cast-iron pipes, 4 ins. in diameter, became closed in seven years, and those of much larger diameter became seriously reduced in the same time." In R. D. Wood & Co.'s handbook, I find a quotation from the Report for 1852 of the City Engineer of Boston, relating to some pipes which had been exposed to the flow of Cochituate water for nine years. It reads: "Some of the pipes were covered internally with tubercles which measured about 2 ins. in area on their surfaces, by about ¾ in. in height, while others had scarcely a lump raised on them."

I have found it interesting to compute from Mr. Duane's data the the values of the friction factor f in the equation $h = f.\frac{l}{d}.\frac{v^2}{2g}$ for loss of head due to friction. I find—for the clean pipe, $f = .0146$; for the tuberculated pipe, $f = .0281$; bearing out very closely Darcy's conclusion that the friction is doubled by these formations or deposits.

If, however, we compare these figures with the values of f found from Darcy's formula—

$$f = 0.01991 + \frac{0.001666}{d}$$

(for clean pipes)

we have $f = .0146$ from the experiments, as against $f = .0203$ from the formula. But it is quite likely that this formula is slightly in error for so large a pipe. Merriman's "Hydraulics" contains a table, compiled from the discussions of Fanning, Smith and others, from which we find the values of f for clean 48-in. pipes as follows:

$v =$	1	2	3 ft. per second.
$f =$	.017	.016	.015

or slightly larger than the value found from the experiment (in which $v = 1.78$).

JAMES DUANE, M. Am. Soc. C. E.—Unfortunately the criticisms on my paper on Tuberculation reach me at a specially busy time, and accompanied by a request from the Secretary that a reply be returned as speedily as possible. Under these circumstances it will be impossible to do more than answer the most salient points brought out by the discussion. Replying to Mr. Brush and others who urge that undiscovered leaks of considerable magnitude may have existed, thus throwing suspicion on the value of the deductions from my experiments, I would say that this possibility had been carefully considered, and only after a thorough personal examination was the statement made that the leakage in this special case is believed to have been practically inappreciable.

The Tenth Avenue mains were laid on good foundations and for nearly their entire length in excavation, only a very small portion being laid on embankment, which had been carefully prepared. More were laid on embankments of poor material or loose rock. On both sides of these pipes for the entire distance, and but a few feet from the outside lines, sewers were built at a lower level than the bottoms of the pipes. It is believed that, had any serious leak existed, these sewers must certainly have intercepted it. A careful examination of the sewers during a dry spell and when the country drained was but sparsely settled, so that the natural flow into them was of the lightest, failed to show any leak of importance—which it is believed could not have failed of detection had it existed. So much for the probable leakage in the general system.

For the compound main that furnishes the data for the paper under discussion, even more satisfactory evidence of non-leakage is fortunately available. In 1890 this main was shut off for several days while a connection was being made with the Aqueduct at Eighty-fifth Street, and during this time the leakage, as determined by the fall of the water-surface in the pipe, was rather less than 3 000 galls. per day (a very small fraction of 1 per cent). This included evaporation from three water-surfaces. As the actual working head on the main was but 6 ft. greater than at the time this observation was made, it is obvious that the leakage was not much greater at the time when the flow was observed.

The gates feeding this pipe were all accessible and were carefully

examined, showing no appreciable leakage into the pipe. Therefore it would seem that the comparative losses of head due to friction in the smooth and rough pipes had been accurately determined and were practically reliable.

Prof. Merriman's point that the value of "C" should vary with the velocity seems to be well taken. But, with all due deference to such eminent hydraulic authorities as himself and Hamilton Smith, it is believed that the actual variation was less than he seems to assume—well within the 2% limit set, I firmly believe. The discharge through these mains, as observed last fall, was checked by the flow through the Aqueduct at Sing Sing, but no statement of this fact was made in the original paper, as it seemed desirable to avoid all unnecessary detail.

Suffice it to say here that the results then obtained indicated that the old value $C = 96$ still applied within 1 or 2 per cent.

The statements of Messrs. FitzGerald and Brackett that tar coating has not furnished an efficient protection against tuberculation in their practice seems in the light of our experience here to be a little remarkable, to say the least. We have coated mains that after thirty years' use show no signs of tuberculation whatever, and of the many mains examined, of all sizes from 6 ins. to 6 ft., I do not remember a single instance of tuberculation in a tar-coated pipe where the surface had not been carelessly injured, and in that case the tuberculation was confined to the parts from which the coating had been removed.

Mr. Trautwine's admission that Kutter's formula for the value of "C" in the Chezy formula is, indeed, very complicated, is a practical concurrence with the opinion expressed in the original paper.

He recommends the use of a diagram for obtaining the value of "C" after having made our guess at "n." That users might make a correct guess at this value appropriate to a badly tuberculated 48-in. main was the motive that prompted the presentation of this paper to the Society, and it is hoped that all other members having similar data at command will submit it in like manner, as such data drawn from observations on the actual workings of real water mains in active use is apt to be far more satisfactory than is much of the data from which the coefficients in our present formulas have been deduced.

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(Vol. XXVIII.—April, 1893.)

RAILWAY SIGNALING.—DISCUSSION ON PAPER No. 560.*

By FOSTER CROWELL, H. G. PROUT, O. F. NICHOLS, H. S. HAINES, T. H. GRANT, THEODORE VOORHEES, GEORGE R. HARDY, C. W. BRADLEY, E. E. R. TRATMAN, HENRY JOHNSON and JOHN P. O'DONNELL.

FOSTER CROWELL, M. Am. Soc. C. E.—I should like to ask Mr. O'Donnell whether in England there are any of what we call automatic signals apart from the lever systems in use?

Mr. O'DONNELL.—There is now being placed on the Liverpool Overhead Electric Railway, on the Timmis patent system, with secondary current, a complete system of electric automatic signals. The Board of Trade limits the experiments of railways as far as, or rather where, the safety of the people is concerned. The Fresh Water Railway of the Isle of Wight is fitted up with automatic signals. When General Hutchinson, of the Board of Trade, inspected it, he ordered the system

* Railway Signaling as Applied to Large Installations, by John P. O'Donnell, M. Am. M. E. Vol. XXVII, page 516.

taken out, and it has not since been restored. The primary current was then used, and a description would be interesting. Here you are rather in favor of the use of the automatic pneumatic system.

H. G. PROUT, M. Am. Soc. C. E.—I was quite interested in what Mr. O'Donnell said about the economy of levers that he had introduced at the Waterloo Installation. It has been one of the special points with the American signaling engineers to economize levers, and they claim that in recent large plants that have been put in they have been able to reduce the number of levers very much below what would have been used in England, there being a like amount of work. That is done by causing one lever to move two switches in a cross-over between two cars; or in causing one lever to unlock the switch, move it and lock it again. My own notion has been that our signal engineers were overloading their levers and were overdoing their economy in that direction. I should like to know Mr. O'Donnell's opinion on that subject.

Mr. O'DONNELL.—I have made it a special object to follow the different improvements and stages of investigation in this country, although I have never been here before. With reference to the remarks of the last speaker, in regard to unlocking a pair of switches, working them and locking them again, that was the first system adopted by English railways. That you will find on the majority of foreign lines, and especially in Ireland. The English Board thought the operation of the switch should be distinct from its locking, the reason being that if the rod broke there is one chance only; the switches would not be locked and the signal might be lowered and the train go over the switch, and the Board of Trade says that if the rod operating the switch breaks, it might lie off the wrong direction, or be partly moved and not lie right for either track. The movement in the signal box is sufficient to operate the lever. This is not a case that is hypothetical, because many such an accident has occurred in England.

With regard to selectors as fixed on the ground, they are not practicable; they overload and are not a saving. The selectors used at Waterloo are in the signal cabin fixed under the tail of the lever. There are only six gear levers in the 236 at Waterloo. There are, I think, 150 levers saved by their adoption; and, apart from any saving in mechanism, the cost is greatly lessened and also the distance through which the levers are operated. In course of time it would mean a tramway to go from one end to the other. Under normal

conditions only four operators are employed, never more, and at certain hours but two. In very busy hours, from 9 to 11 A.M., or from 4 to 6 P.M., when the people are going to the city and returning from it, then four are required.

O. F. NICHOLS, M. Am. Soc. C. E.—How are the connections made at the Waterloo station, by pipes, or by a set of wires ?

Mr. O'DONNELL.—The custom is to operate sets of wire. If you operate the signal by rod and take out the lever, you can hardly expect the signal to draw back 200 or 300 ft. of rod. The Board of Trade rule is that the signal must be operated by wire, and it must be of such a nature that the balance arm must return to the danger attitude in case of a fracture.

Mr. NICHOLS.—On many important lines—short lines running a great number of trains—the difficulty is that the signal stations become very long and difficult to operate with piping, and the levers become, as Colonel Prout has said, very much overloaded. Operating a long line of piping, reaching 1 000 ft. in length, is not easy work on the lever. On the other hand, there are instances in using the wire system of the fireman getting out of his cab to set the signal, this being permitted by the slack in the wire.

Mr. O'DONNELL.—If such a case occurred in England, if an engine-man left his engine and operated the switch, he would be dismissed. I hope the Society will not misunderstand me when I say that condoning any operation of that nature is very severely to be condemned. We do not allow discretion to the engine-man at all. If his signal authorized an accident, he could not be blamed in effecting it.

Mr. NICHOLS.—That is the practice on the best lines in this country.

Mr. O'DONNELL.—I thought that the Train Rule Committee of the Railway Commission was especially constructed for the purpose of drawing up such rules as would place engine-men amenable to punishment if they went outside of them. In England every railway official, from the general manager down to the telegraph operator, has a book of rules in his pocket and has to sign for them.

Mr. NICHOLS.—In this country we cannot be as radical, I suppose, as they can in Great Britain and some other countries in administering absolute punishment by law. Here the case would come before a jury, and a man's personal appeal, or the condition of his family, etc., operate, and the man escapes scot free. In England the punishment is

more certain to follow, I think. There is a growing tendency here, I believe, to have strict rules laid down and have them rigidly enforced, and leave the engineer little discretion but to obey. It becomes more and more necessary that the man in the tower should be the arbiter of the destinies of the people on the trains.

The various interlocking companies in this country are very well managed and generally they have very efficient signaling engineers in their employ. One of the difficulties we meet in dealing with these gentlemen is that there are some four or five different systems. The Saxby and Farmer machine was the first to be introduced in this country, and growing out of that there have been improvements and changes made by several companies which have led to the use of five or six different systems of interlocking with great want of uniformity in constructing and handling them.

Mr. O'DONNELL.—We have gone through the various stages in England that you are speaking of. We are in a more fortunate position in reference to the Board of Trade, who say to the different companies, "We want that result; get it how you can, so long as it satisfies our requirements." We invariably insist on the use of a distant signal. In our opinion it is almost the most important signal on the railway. It is the only one that can be passed when it is at danger. Whatever its condition, it may be passed. It is simply an indication, 800 yds. in the rear, of the general condition of the home signal. The distant signal usually rules the home signal. If the distant signal is in a safety attitude, you may take it for granted that the home signal is also; but if it is in the danger attitude, that may not be the condition of the home signal.

Mr. NICHOLS.—One of the troubles in this country is in being obliged, at times, to allow the engineers discretion as to whether they shall pass the signal or not. Having the distant signal the same color, or allowing an engineer to pass it under certain conditions, gets him into the habit of thinking he may pass the signal at any time with impunity. I think the tendency in this country is to abandon the distant signal on lines requiring rapid movement of trains in which two signals at the danger point are to be noted. No case occurs to me when the same color is used for the signals. I think a different colored light, something like the purple light used in the shunting signal, should be used for distant signals, to make it a special and distinct

signal. This would be preferably the green cautionary signal now frequently used.

Mr. PROUT.—I really believe Mr. Nichols is at fault in that respect. I do not believe there is a case in the United States of a distant signal with a square end that an engine-man is allowed to pass. A distant signal is painted green and has a fish-tail end. There is this exception, which may have misled Mr. Nichols: on many roads it is the custom to protect the facing points by signals placed some way in advance; a main line train can never pass the signal when it stands at danger, but a freight train destined for that siding may go slowly by and take the siding. But a distant signal, painted red, which a trainman is allowed to pass, I do not think exists.

Mr. O'DONNELL.—I was about to agree with the remarks of Mr. Nichols that under some circumstances the distant signal is an anomaly. I once wrote a paper in which I pointed out that such things should not occur. The distant signal outwardly, at night, so far as England is concerned, is the same as the home signal; unless the engine-man knows his location, he may mistake the distant for the home. In this country the distant signal is fish-tail and is painted green. A distinctive character should be given by day and night to the distant signal. The giving green as the danger position by day appears to me to be more in accordance with the special attitude of the signal. When they follow that out by night, as I should suppose they should, I do not know, I imagine they would give a green light for danger. The only question that arises is that they use green for the caution or safety attitude for the automatic signals. If that is so, the anomaly then comes in that you have the danger position for the distant signal by night green and the "all-right" position for other signals green. I think Mr. Haines says that green is the color.

H. S. HAINES, M. Am. Soc. C. E.—Mr. Chairman, I did not come here to-night expecting to hear a criticism of the address which I made at the recent meeting of the American Railway Association. These remarks were not intended as the opinions of an expert on block signals, because I did not represent myself as an expert in such matters. I had only intended to point out the difficulties which our standing committees have experienced in discharging the duty imposed upon them, of compiling a book of rules for the guidance of railway employés in the operation of block signals. In doing that I had to

keep in mind the restrictions which controlled our committees in compiling these rules. They are the same limitations which were imposed on us in preparing the book of standard train rules, now so generally used in this country; that is to say, that it should embody only the recognized practice. I think if the gentleman will keep that in mind in reading over the remarks to which he has referred, he will see why I stated the subject as I did. For us to attempt to operate our roads in accordance with what we understand to be the rules established by the Board of Trade in Great Britain, or upon the lines estimated in the gentleman's remarks, would mean bankruptcy to some of the railroad companies in this country; many of them could not raise the money to provide such an installation as would be necessary to conform to those requirements. It is for that reason that I referred to the time interval as in general use in this country, and the conditions under which our railroads are operated are such that it is imperative that this should be so. It is only in the vicinity of large centers of population, where the train service is frequent and conducted over two or more tracks, that such expensive installations as the gentleman has described could be expected. If you will permit me to say so, the interlocking switch system is one thing and the operation of trains on the main line under block signals is another, and the rules that we are now seeking to prepare in our Association are intended for the operation of trains on main lines, not particularly for the control of interlocking switch systems at terminal stations.

Pardon me for the time I have taken in making this explanation of the position I assumed in my address. I would add that I have listened to the gentleman with a great deal of interest.

In the reference that he made to my remarks about distant signals he has referred to interlocking switch systems rather than to the movement of trains under the block system on the main line; but if the block signal is visible at a distance sufficient for a train to be stopped before passing the signal which is at danger, then a distant signal is not necessary for the safe operation of trains. It is only when the block signal is not visible at a sufficient distance, or when trains are so numerous that without it the traffic of the road would be delayed, that a distant signal on the main line is absolutely necessary. This has been accomplished, I should say successfully, in what we know as the pneumatic automatic system. Any one who will observe that sys-

tem in actual use will see how the block signal in one block is used as the distant signal for the block ahead. I learn from the gentleman's remarks that in England that system does not meet with favor with those who are considered authorities in such matters, but that preference is given to the controlled manual system. It seems to me that in this country the tendency is toward an automatic system, and for one reason that it does to a great extent eliminate human agency, which is an advantage in the operation of railroads in two ways—that it minimizes the opportunity for human error, and that it materially decreases the cost of operating a system of block signals.

There was one point the gentleman touched on, to which I wish he had devoted a little more time, and that is, as to what I might call the preliminary notifications that are given by signal in an extensive terminal station to those who are interested in knowing what the next movement is to be. I understood him to say that the system of signals in the installation described by him provided for an intimation to the men on the platforms as to what they might next expect. I do not understand from his remarks just how that was managed, what information was conveyed, and by what means.

I would make one point more, that is, as to a uniform system of signals. The gentleman has referred to the fact that the distant signal, as used in England, is somewhat of an anomaly because it requires an engine-driver to pass a signal set at danger. Now, one trouble which we have encountered in our Association in preparing a set of rules is that the development of train signals has proceeded from several independent centers, and they have not followed the same general principles. As, for instance, there are important railroad systems in this country in which the signal for "line clear" is the green light, which on others is either a cautionary or a distant signal. I mention this as accounting for our not having a uniform system of signals. That is something very desirable to attain, and which I supposed had been established by Government authority in England. If attained at all in this country it must be by concerted action of the railroad companies, as through the American Railway Association.

I was also interested to learn that there was no such thing as an absolute block system in England. I understood the gentleman to say that they permit more than one train in the block at one time. If that is permitted by a signal, then, under the ideas that are beginning to

prevail with us, that is not an absolute block system. Perhaps I misunderstood him.

Mr. O'DONNELL.—What I said in my paper was that in certain circumstances in England, the permissive block system is used. During April there occurred in New York the Columbian celebration. I should like to ask the railway managers in this country whether they maintained the absolute block system in bringing the people into the city? The answer is, they did not; and it is under those circumstances that we do not in England. I, myself, maintain that a railway should be conducted for the safety of its passengers and not for the shareholders. The permissive block system is used only on such days as the Derby Day, and the Oxford and Cambridge boat races, when the enormous traffic could not possibly be handled under the absolute block system; the permissive block system is used, but without authority. The difference between the absolute and permissive is that in the absolute block system a clear section must be maintained by trains. That is to say, that if you have three sections, *A*, *B* and *C*, and you have a train leaving *A*, you cannot have any in *B*, the previous train must be approaching *C* before you can allow the *A* train to approach *B*.

Mr. PROUT.—Passing only by the danger signal?

Mr. O'DONNELL.—Yes.

Mr. PROUT.—How long?

Mr. O'DONNELL.—I ask Colonel Haines if there is any railway in this country that runs on a time interval.

Mr. HAINES.—I think it could be maintained that where a train is permitted to enter a section under a block in which there is another train already, that is, to a certain extent, a time interval. It requires you to protect the rear of every train in the same way that you would protect the rear of the train where you run trains under a time interval without block signals. The distinction that we are inclined to draw is that an absolute block system does not authorize one train by signal to enter a block in which there is another train; that a second train can only enter with a special order. That is, that where, under any circumstances, one train is permitted by signal from the signal tower to enter the block in which there is at the time another train, that is a permissive system.

While I am on my feet I will read a note that has been handed me. It is a statement that on the Third Avenue road last Wednesday 12 000

engine-miles were made, the road being 8 miles long, with two tracks, and 750 trains each way in 24 hours.

Mr. O'DONNELL.—In taking the Elevated Road the only lines we can pit against it is the Metropolitan Underground Railway in London. With reference to the question of time interval, it means the lapse of a certain amount of time. The permissive system has no reference to the time interval, because it is covered by signal, either permissive or absolute; and if the train was delayed for an hour inside, while it is the permissive block system, the train, a few hundred yards in the rear, would also be delayed. It is time interval, if you like; but it is not governed by specified time.

Now, as to the distant signals. Mr. Haines cited an automatic system in this country in which the distant signal was not needed. If there is any gentleman here on that road, he will bear me out that the pneumatic system there has never been a success. In the Woodlawn system they were all free; they were all free on the Bound Brook line.

THEODORE VOORHEES, M. Am. Soc. C. E.—We had some 7 miles of the Hall automatic system put up some two years ago, and it was all put up with distant signals.

Mr. O'DONNELL.—That bears out what I say. I was about to remark that while I don't wish to appear a prophet from the experience in England, you will come to distant signals in this country as sure as I am here to-night.

Mr. VOORHEES.—On the subject of distant signals, you stated that the usual distance in England was 800 yds.; is that the usual distance from the home signals? I would ask also whether the single signals are worked by a double wire?

Mr. O'DONNELL.—That is the specified distance by the Board of Trade; if the signal boxes are at a sufficient distance to warrant it, 800 yds.; on a down grade, 1 200 yds. There is no single distant signal, to my knowledge, in England, which is worked with a double wire; we never use a double wire. I once operated a signal a distance of 1 mile; we used a capstan and wheel. But the usual run of signals in England is usually 800 yds. In the signal boxes we use an adjuster which the signal-man operates as he finds the signal is not working; if there is a 50 or 60 lb. weight at the end of the arm, that is sufficient to put the arm at the danger attitude. We do not have such extremes of temperature as you have here. The extremes of temperature are

not such as to give us any great difficulty. We have a difference of wire occasionally, amounting, perhaps, to 10 ins.; that is not sufficient to make the arm come off. Our practice is one wire, and I think that if expansion and contraction is to be a difficulty, it is equally applicable to one or two wires; they are both being expanded and contracted.

Mr. VOORHEES.—The experience has been in this country, so far as my knowledge goes, that a single wire does not operate successfully. We have had considerable experience with single wires running to ½ mile, and they have not worked well. We are using the double wire now, but limiting the distance to 1 600 ft. We find it difficult to operate double wire to any distance greater than 1 600 ft., on account of expansion and contraction.

T. H. GRANT, Assoc. M. Am. Soc. C. E.—While the majority of railroad engineers naturally regard England as the home of modern signaling and interlocking, they may properly question whether there exists in this country, on well-regulated roads, the looseness and want of method that may be inferred from this discussion.

The signals on the Central Railroad of New Jersey between Jersey City and Bound Brook, a distance of 30 miles, may be taken as a fair example of American practice. This part of the road is under the operation of the automatic pneumatic system, the first section, from Jersey City to West Eighth Street, Bayonne, having been put in service in the spring of 1889; and the second section, from the latter point to Bound Brook, during the past summer. The signals which govern the running of trains on four tracks nearly the whole distance are located from 1 200 ft. to ½ mile apart, depending upon local conditions. There are two blades for each track, one over the other; the upper, or red blade, and the lower, or green blade. If both are extended horizontally to the right, it is indicated that the two blocks ahead of the signal are occupied, and no train or engine may enter the block. If the red blade has dropped and the green blade is extended, the train may enter the first block, knowing the second is still occupied. If both blades are down, two blocks are clear. The signals are operated by compressed air from three power stations in connection with electric track circuits.

The movement of trains over the same part of the road is further governed at junction, crossing and terminal points by thirteen towers for the working of interlocking switches and signals. The system is

practically the same at all towers, although there are some points of difference in the machines built by the various signal companies. While there may be a Saxby & Farmer, a National, or a Johnson machine at a particular point, there is no external evidence to the trainmen of any difference from any one of the other towers. It is, therefore, proper to say there is an uniform system.

The largest and most important tower is located at the Jersey City terminus. It operates by means of a 72-lever Saxby & Farmer machine, the signals and switches in front of the train house. It is supplemented by another tower, containing a 48-lever National interlocking machine, about 2 000 ft. further up the yard, at which point the passenger trains are shifted and made up, and the Lehigh Valley and Newark trains let in upon the main tracks.

Two other towers, one at Jersey City Junction, 1 mile out, and one at Claremont, 2 miles from the train house, complete the interlocking system at Jersey City. The remaining nine are distributed to cover junction and crossing points.

At points where switches, crossings, etc., controlled from a tower, come within the territory protected by the automatic signals, it is so arranged that the two systems must work in unison. A lever-man cannot give a clear route to a block while the automatic red blade for that block is at danger.

The company spares no expense to make its employés fully acquainted with new signals, for this purpose issuing books of instruction and rules, and requiring strict adherence thereto. The signals, connections, interlocking, etc., are carefully looked after in all their details and maintained in good working order by a supervisor and a well-organized and sufficient corps of assistants.

Mr. O'Donnell.—I gather in the last remarks that you have stated that four of the different companies have all put up signals. Now, the Hall system is radically different from any other system. It is purely electric. In describing the pneumatic system at Bound Brook you mentioned that there were permissive blades and absolute blades. They are precisely the same as those used with the pneumatic plant at Woodlawn.

Mr. Voorhees.—I cannot very well sit here and let pass one observation the gentleman made. As the only representative here, so far as I have been able to discover, of roads entering New York City from

the north, I wish to state that, so far as I know, all the trains on the Hudson River Railroad and the New York, New Haven and Hartford Railroad carefully observe the block system; the Hudson River is governed by the absolute block system. I have carefully observed the pneumatic block plant that we put in from Mott Haven to Woodlawn ever since it was put there. We cannot work it under any absolute rules. We found that we had to make it the rule that engineers could pass the block signal when at danger, provided they waited a time interval. I do not think it possible to work any automatic signal except under such a rule. It is under that view that the New York Central and Hudson River Railroad has gone into the Sykes system from New York to Buffalo, which is now under contract.

GEORGE R. HARDY, M. Am. Soc. C. E.—Mr. O'Donnell's paper is a very interesting one, and the explanation which followed the reading of the paper touched upon the subject of the position of the semaphore, concerning which there seems to be considerable variation in practice. It would seem that in conformity with the principle of organizing signal systems with the largest degree of uniformity as pertaining to those characteristics which are observable by the enginemen or drivers, that we should have a constant rule in regard to the location of the semaphore which can be easily understood at first glance. The rule which has been applied to a great many railroads, and concerning which there can be as little difficulty in its application as any, is to provide the semaphores as nearly as possible over or just to the right of the track on which the train is approaching. When the roadway consists of three or four or a larger number of tracks, this necessarily demands that a signal bridge should be constructed so that the standard signals may be placed above the tracks, although small or dwarf signals might be placed on the ground between the tracks. With this arrangement it is sufficiently clear to any engine-man that no other signal than the one he is so directly approaching relates to his track. If the signal he approaches is simply a block signal, governing no variety of routes, it is unnecessary to make any other arrangements for indicating the route it relates to; but if an arrangement of switches makes it possible to use one of two or three or four routes from the approaching track, then the practice of placing all of those signals relating to the same number of routes on the same pole in the same position, as for one signal, is much better

than to make two or more independent posts for the various routes; because, as soon as the latter plan prevails, the space allotted to the signals belonging to the neighboring track is imposed upon, and if a neighboring track should require many signals, some of them might be crowded completely out of proper position relative to the track to which they relate.

The answer in objection to this arrangment by some parties is that the high-speed route should require a most conspicuous signal. We grant this criticism, and favor the use of emphasizing the signal for that route of a group of routes which, being the highest speed route, requires the largest degree of convenience for the engine-men. But this determination of which signal of several on one post applies to a particular route may easily be provided for under one of two rules. The first rule is to place the signal for the extreme right-hand route at the top, and the others in natural sequence below for the routes further to the left. Some roads vary this rule in applying the rule only to the slow or switching routes, and always putting the high-speed route at the top of the post. We think the situation is best adapted to all circumstances by adhering exactly to the rule as first indicated, and for the sake of giving more convenience for determining which signal governs the high-speed route, that signal can easily be made larger than the signal for the slow routes, both in length of semaphore and by manner of lighting at night. The slow or switching routes may be lighted by simply illuminating the blade with reflected light. All of the above suggestions are in actual and successful practice during a period of several years, and, as far as I know, no sufficient grounds of criticism have yet been established to modify the same.

The subject of distant signals is a matter which is not usually so well analyzed as it might be. Not undertaking an exhaustive discussion of this point, I will only refer to one or two points in this connection. The right to pass a distant signal at "caution," as indicated by the horizontal position of the distant signal, is a right which may be used by an approaching train, providing the extent of observation of the track commanded by the engineer is sufficient to enable him to know that the track is clear, and that he proceeds only at a speed which will enable him to stop within the clear track which he can see—"Proceed only as the way is known to be clear." Thus he may approach to the home stop signal, and at that place wait for orders.

This practice with regard to the distant signal does not modify its purpose at all, as some have supposed. The great value of the distant signal is that, when cleared, it offers definite assurance that the speed may be maintained into the territory controlled by the next home signal. While the distant signal remains at "caution," the rear of a train which has drawn entirely past it has the same protection that the engineer of that train afforded when he passed it at "caution," knowing the way to be clear. But when a train which has passed a distant signal has to back up, then it is absolutely necessary that the flagman should first protect the whole space to be used by such back-up.

We are unable to appreciate in detail the conditions under which the movements are managed at Waterloo Junction, but if the information which was hinted at during the discussion, that the engine-men conveyed to the signal-men what they wanted to do, it seems to us a large digression from the advantages of using interlocking apparatus. We had supposed that the English practice was ready to take advantage of introducing engine control from one standpoint over all the business of switching or work done on the tracks controlled by an interlocking apparatus. In other words, some one so authorized should by signals direct all the yard-work or movements of trains. This has been successfully accomplished at many places in this country, and on a large scale.

We regard the business of making fly switches with passenger trains under interlocking appliances as an unfortunate arrangement which we doubt has as yet been divested of the elements of danger. The most conspicuous case of that kind in this country, so far as we are informed, appears to be continued in conformity with some prejudice as to permitting the locomotive to run into the train-house where the smoke would be objectionable. If such practice should be changed and the tracks and connections be rearranged, we are certain that the same areas might be made to furnish facilities for accommodating a large increase of train service with less interruptions.

At Waterloo the right to use the incoming tracks for movements in the opposite direction appears to have been provided for by a special description of signal as well as some other attachments. Our contention in this regard is that such advantage in using the territory controlled by the interlocking does not require the use of any new devices to be exhibited to the engine-men, but that the combination of well-ex-

pressed rules and the signals of limited variety and uniformity, will provide all that is needed.

Mr. C. W. BRADLEY, Assoc. M. Am. Soc. C. E.—I have been very much interested in the paper of Mr. O'Donnell, and the discussion has taken such shape that I almost think this is a meeting of our Train Rule Committee. As a member of the Train Rule Committee of the American Railway Association, we have now in hand the question of a standard code of rules governing the operation of the block and interlocking signals on our American railways. We have found so many devices and appliances that the Committee are almost at a loss to know just what to recommend, or how we can formulate a code of rules that will cover all the appliances and conditions of the service. The standard code of train rules adopted by the American Railway Association, and now in use on 75% of the railroad mileage of this country, is a great advance in the operation of our roads. Whether we can do as well with the rules governing the use of signals is an open question. Mr. O'Donnell has given us a good many good points. We are now looking for some device that will not only interlock the signals, but will interlock the engineer or driver as well, and I would ask Mr. O'Donnell if they have any such device in use in England.

Mr. VOORHEES.—We have been groping in the dark on the rule question, and I would like to ask a question in regard to that. As I said before, the Hudson River Road is under the absolute rule not to permit an engineer to pass a red signal when at danger. But we have often run against a case where the red signal could not be brought to safety by reason of a failure in the electrical apparatus, and the question was whether to let the train stay there all night or get a rule that would not delay the traffic.

Mr. O'DONNELL.—There is a rule.

Mr. VOORHEES.—I have studied the English rules very carefully. Have they got such a rule ?

Mr. O'DONNELL.—The station-master issues instructions to the engine-man, I believe.

Mr. VOORHEES.—We undertook at first to permit trains to pass at the display of a green flag from the cabin, when the man in the cabin knew that the block ahead was clear, but was unable to move the signal.

Mr. O'DONNELL.—You can lay down certain rules authorizing the driver to pass such a signal if it cannot be lowered. It would have to

be worked in conjunction with the automatic Sykes system. You would have to break the glass and press the button. I don't know whether you would permit a man to do that.

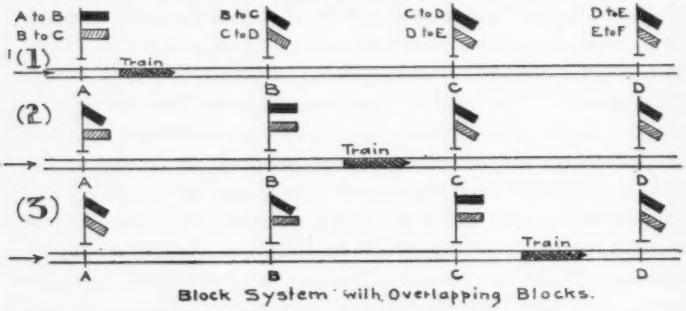
Mr. VOORHEES.—We do not permit a man to do that under any circumstances. We don't allow him to unlock himself.

Mr. O'DONNELL.—We allow him to do so, but by a time gauge which registers against him. He might do it 10 times.

Mr. VOORHEES.—We first made a rule that a man might pass if a green flag or light was displayed toward the approaching train by the operator in the cabin. Experience taught us, however, that there was danger of this signal being misunderstood by the engineer of an approaching train, and our present rule obliges all trains to come to a full stop unless all signals are clear, and not proceed without a written order from the operator.

E. E. RUSSELL TRATMAN, Assoc. M. Am. Soc. C. E.—The present lack of uniformity in codes and rules is shown by Colonel Haines' remarks, and while it is true, as Mr. O'Donnell says, that railway officers are left to themselves to prepare rules and adopt methods for their own lines without regard to any standard system, it seems not improbable that the development of the work of the Interstate Commerce Commission may result in a certain amount of government regulation of railways, under which a standard code and system of signaling would almost certainly be adopted. The adoption of a standard system does not imply absence of competition, as the regulations would merely require that certain specified results must be obtained, and that the plant must meet the approval of the engineers of the regulating body. This is the system in England, where several signal companies carry on business and have their own specialties. Mr. Bradley remarks, jokingly, that it will be necessary to interlock the engine-men; but, as a matter of fact, they must be so interlocked morally, by being educated to habitual observance of, and absolute obedience to, the signals. In this way alone can the highest efficiency and safety be ensured. There are signal devices to practically interlock the engine-men by applying the brakes, sounding the whistle or smashing the headlight glass; but the advisability of the use of such devices is very questionable. For special cases, however, an apparatus which automatically places torpedoes on the rail while the signal is at "danger" has advantages which must not be overlooked.

In this country we are specially interested in the introduction of an efficient and economical system for single-track lines with more or less disadvantageous financial circumstances. This has led to the introduction of the Mozier system on the New York, Pennsylvania and Ohio Railroad, and the Lattig system (National Switch & Signal Company, Easton, Pa.), which is applicable for either single or double track working. The Lattig system is a promising combination of manual and automatic working. By means of an adaptation of the electric slot, the signal is automatically set at "danger" by the passing of a train, and cannot be lowered by the signal-man until the train has passed on to the next block. In other words the signal is automatically set and maintained at "danger," but is lowered by hand power only. To get the best results the block system must be in general use. If an engine-man runs 100 miles by train orders and then 20 miles by



Block System with Overlapping Blocks.
Central Railroad of New Jersey.

signals, he is not likely to give due attention or obedience to the latter. Where the system is in use, the notoriously inefficient plan of sending back rear flagmen should be abolished.

The hand-operated system of signaling is by far the best and puts a check upon the engine-man, who is less likely to disregard the signals under the eyes of a signal-man who will report the occurrence than to disregard an automatic signal which can tell no tales. Automatic signals may be applied at certain places and for special purposes, as at crossings of street railway and steam railway tracks, etc.; but it does not seem advisable to use a complete automatic block system for main track operation. In the event of any failure of plant the automatic system is inert and useless, while with the manual system there are men to take action, provide against accidents and straighten out any

tangle of traffic. The automatic system on the Central Railroad of New Jersey, which has been referred to in the discussion, was described by me in *Engineering News*, New York, March 29th, 1890. The signals are operated by compressed air, with a cylinder and gear for each arm attached to the signal posts, the valves being controlled by electricity. It is arranged with double or overlapping blocks, and the sketch on opposite page shows the operation for one track. At the end of each block is a separate post for each track, and each post carries two blades; the upper blade (and lamp) red, and the lower blade (and lamp) green, the lamps showing white when the blades are lowered. When a train enters the block *AB*, both blades of post *A* are automatically set at "danger" (Position 1). On entering the next block *BC*, both blades at *B* are set at "danger," and the top blade at *A* is released (Position 2). On entering the block *CD*, both blades at *C* are set at "danger," the top blade at *B* is released, and the lower blade at *A* also released (Position 3). Thus, an engine-man can see whether one or two blocks are clear. The rules provide that an engine-man passing a signal with the red arm down and green blade up must slacken speed and prepare to stop at the next signal, expecting to find both blades at "danger." Through disregard of this rule an engine-man was not able to stop his train at the signal, December 8th, 1892, and ran into a train on the next block, causing a serious accident. Automatic or other signal systems which require special fittings to the locomotives (to apply the brakes, sound the whistle, etc.) should not be considered for ordinary main-line working, at least.

The semaphore should be the standard form of signal, as it is the accepted form in general use in this country and abroad. In most cases the blades are pivoted at the end and provided with a counter-balance; but on the Great Northern Railway of England they are pivoted at the middle and stand vertically for "track clear." A red blade with white square near the end is more distinctive than an all-red blade. White is the best color for the posts, as any other color tends to kill the brightness of the color of the blade. The normal position of the blade should be at "danger." As to the question of position-signals by night and day, the Koyl parabolic semaphore (National Switch and Signal Company) generally shows an inclined white streak of light for "track clear," and a horizontal red streak for "danger"; but the red might be eliminated and the position alone of

the streak of light used as the signal. The Union Switch and Signal Company has an illuminated semaphore, with a hollow box blade, having a strip of glass in the front, light being reflected from the lamp on the post into the blade, and also (if desired) into the ordinary lens. The Boston and Albany Railroad and Old Colony Railroad use three lamps to each signal. The former has two white lights in a horizontal line for "danger," and two green lights in a vertical line for "track clear"; while the latter has two red and two white lights, respectively. This arrangement has the objection of expense. Note that the Boston and Albany Railroad uses white for the "danger" or "stop" signal.

The signal lamps should have large lenses, and at large city stations, where numerous electric and gas lights are almost certain to be visible, it may be desirable to abolish the white signal light, or else make it the "danger" signal, so that engine-men would be on the look out for a colored light. The Midland Railway, of England, uses red for "danger" and green for "track clear." The distant signal should be distinctive by day and night, and this is a matter of consideration, as at present the home and distant signals are distinctive by day only. In view of the increase in the number of high-speed heavy trains, it becomes necessary to arrange for signaling them so as to ensure their being able to pull up at a "danger" home signal. From the official reports of the Board of Trade (England) inspectors upon all railway accidents in Great Britain, much may be learned in the way of providing against defects and accidents which occur with the very complete signal systems in England, and the Society ought to, if it does not, preserve these reports regularly for the library.

While the equipment of main tracks with block signals is very desirable, it is especially necessary to provide interlocking switch and signal plant at terminals, junctions, track crossings at grade, and drawbridges. The Board of Railroad and Warehouse Commissioners of Illinois requires this protection for grade crossings, and a set of rules and regulations on this matter has been prepared by Mr. Charles Hansel, engineer to the Board. The frequent accidents at grade crossings of steam and street railways show the insufficiency of gates and gatemen, and suggest the use of automatic signals and derailing switches on the street railway, operated by trains on the main line.

In case of failure of plant or other reason preventing the giving of a "track clear" signal, although the block is known to be clear, there should be some rule allowing the signal-man (or station-master) to give a written order or special card to the engine-man, authorizing him to proceed to the next block, due record being kept and report made. This would prevent the stoppage of traffic by a failure of the plant, when the track is known to be clear.

HENRY JOHNSON, Esq.—I have read with interest Mr. John P. O'Donnell's paper and the description of the system in operation at Waterloo Station.

Mr. O'Donnell, however, does not show clearly what advantage is gained by the use of independent signals for different kinds of traffic over the same route. It would seem that the same signal would answer for an empty engine, as well as for a complete train.

Quite a number of blades might have been saved, and the system simplified, by the use of large and distinct indicators for the several routes from any one track, instead of the use of bracketed signals.

In the paragraph commencing at the bottom of page 518, and ending page 519, after saying that the custom in England sanctioning movements in a wrong direction, or, to put it more clearly, an east-bound movement along a west-bound track, or a north-bound movement along a south-bound track, is to perform such movements by special authority, and deprecating the system in use in this country, sanctioning the movement by a mechanical signal, the author goes on to say that in England many accidents have occurred through trains proceeding along the wrong track through ignorance.

It would appear from this that the system which he commends has not proved efficient. He does not state how the special authority is conveyed to the engineer; but, for the information of those who may not know, it may be here stated that it is conveyed by means of hand signals.

The one case which he cites to strengthen his condemnation of the American practice, in my opinion, does nothing of the kind, but on the contrary condemns the system in use in England. He says: "At Kingston, on the London and Southwestern Railway, where an engine-man thought that the crossing points had been moved for him to proceed to the right road, the points themselves had not been

moved at all. He proceeded to the next section on the wrong road," etc.

This would seem to prove the need of some more reliable means of communicating to the engineer that the points or switch had not been reversed and did not stand right for him to cross over to the right road than the one he advocates.

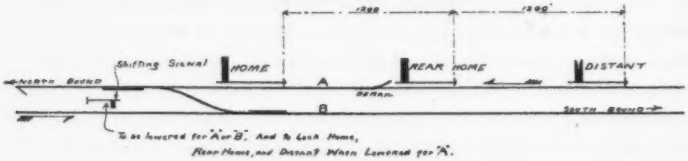
The practice in this country, as stated by Mr. O'Donnell, is objectionable and has long been condemned by some signaling experts; but he is wrong in supposing it to be the general practice. The practice here is to provide signals for all regular shifting movements and is, in this respect, better than the English practice; but in many cases the interlocking is so arranged that such signals cannot be made to authorize a movement, when such movement would lead, say, south on a north-bound track. There is, however, reasonable objection to this practice, and many railroad men claim that such signals should be given for wrong roads to avoid the bad practice of hand signaling.

There are these objections to every present-known practice, and some solution of the difficulty is needed. I suggest the following:

Use the signals in the manner they are now used at Woodlawn Junction, and condemned by Mr. O'Donnell, and avoid the risk he points out by inserting trailing derails on tracks where such movements are permitted, such a sufficient distance ahead as not to derail a train making a legitimate movement, but near enough to derail a train that may be accidentally taking the wrong track. Such derails need not be operated from the towers, but may be weighted open, so that all trains making proper use of the tracks at such points would close the switches when passing over them.

Rear home signals should be placed at such derails, to give an operator the power of stopping an approaching train before entering the field of an authorized shifting movement.

The following sketch illustrates the suggestion:



Mr. O'DONNELL.—In closing the discussion which has taken place upon my paper, I would observe that the majority of speakers at the discussion on October 19th last have revised their statements, and in certain cases they appear to be somewhat different from the remarks spoken at the meeting. I have not revised the statements I made at the meeting at all, but it would have been better if certain of the issues now raised had been raised at the time, when I could have given explanations and could have been criticised again as to any views I hold with reference to them.

Now, however, I regret, as this is the final statement of my views on railway signaling, the opportunity is not offered to others to criticise, otherwise the discussion might be prolonged indefinitely; but I will endeavor, as far as possible, to keep to the lines laid down in my paper. I will, however, take this opportunity to enlarge upon the new issues raised by communications and revised statements since, and give as my reason for doing so that as the matter is new and has been entered as part of the discussion, I claim the right of replying to it.

Adverting again to the remarks of Mr. H. S. Haines, I cannot fall in with his view, that allowing the principle of time intervals in substitution for some form of block working is in any way economical or would tend to assist the companies which are of the poorer class, which he suggests should be allowed the latitude of such privileges as time intervals.

A poor country line whose traffic is very small, possibly not more than three or four trains a day, need not necessarily indulge in such large expense as a lock and block system of signaling; but, on the other hand, there is no reason why they should adopt a time interval, as a time interval would mean no block system of any description at all. The ordinary block instruments for signaling trains from one section to another is not an expensive system, and, as the telegraph installation is down for other purposes, it does not add much to the cost, and there is no reason why a time interval should be adopted on any line in the United States or in any other part of the world. It is generally conceded that an entire line, no matter how cheaply constructed, should have the facilities of a telegraph system; in fact, such a system is generally used in the construction of a line.

It may, therefore, be taken for granted that a time interval proper, as a substitute for block working, is a thing of the past.

There seems to be some confusion as to there being a difference between interlocking switch systems and the operation of trains on main lines under block signals. I would remark that the two are synonymous. The interlocking system is simply interlocking the outside signals with each other and with any conflicting switches. As I have pointed out, immediately you interpose a switch on the main line—and it is to be hoped that every station in the United States, sooner or later, will have switches—you must introduce the interlocking system to have any degree of safety, and this system cannot be automatic because you cannot work a switch automatically, at least not from a practical railway point of view.

I would respectfully suggest to Mr. Haines that if the Railroad Association is preparing rules for the operation of trains on main lines, and particularly for the control of interlocking switch systems at stations, it would be better if the last paragraph were eliminated, as any rules must include the working and the control of the interlocking systems. Terminal stations have no special reference to the matter, for it is not only at terminal stations that interlocking systems would be used. The word "switch" is a misnomer as applied to interlocking systems.

I would take up too much space if I were to reply in detail to the remarks as to distant signals, interlocking switch systems, and the difference between these and the movements of trains under block systems. The remarks at the discussion became so involved in reference to these points that it is better to leave them to a future occasion.

There are few railway men who will agree with the statement that it is only when trains are numerous that a distant signal on the main line is necessary. I must again disagree with the statement, because it is incorrect, that the system in actual use in the United States is that the block signal in one block is used as the distant signal for the block ahead. I am sorry to again remark that this question has become very much involved.

In the automatic system at Bound Brook, the block signal in the rear block is certainly not the distant signal for the block in advance. There are in the signaling arrangements in connection with Bound Brook a stop signal and a distant signal to each block, and they are supposed to answer the same purposes as the stop and distant signal in any other part of the United States; and the stop signal under no

conditions answers the purposes of a distant signal, because each block has its own separate distant signal which may be passed at "danger," whereas no block signal should be.

The question of cost hardly enters into this discussion, as I would venture to say that after a due interval of time has elapsed for the average maintenance of an automatic system of signaling, and a corresponding manual system, that undoubtedly it will be found that the manual system is the less costly, while, at the same time, being infinitely more satisfactory from all points of view.

I am sorry if any remarks I made at the meeting conveyed the sense that I looked upon the signaling of American railroads as being conducted with looseness; want of method I certainly inferred, but not looseness. These are remarks offered by Mr. Grant. He states: "The signals on the Central Railroad of New Jersey, between Jersey City and Bound Brook, a distance of 30 miles, may be taken as a fair example of American practice." Now, I do not think that this can be considered a fair example of American practice, because I believe that the larger amount of American signaling is on the manual system. It certainly cannot be called a uniform system between Jersey City and Bound Brook, as wherever a switch is interposed and controlled it is non-automatic, and, as I have pointed out, there is no unison between the automatic and the non-automatic systems. It must be obvious to all, that such an arrangement as allowing, in the same block section, certain signals to be automatic, normal position "safety," and other signals (which ought to give the same indication to the driver), worked by a signal-man, the normal position being "danger," can hardly be called uniformity of practice.

Mr. Grant cites the question of locking frames as no external evidence to the trainmen of any difference from any one of the three towers. If the point of external difference is an important one, surely the question of the normal position of the arm enters vitally into this question.

The pneumatic system, both automatic and non-automatic, is the last system that ought to be called uniform; it is the most ununiform system of any I have known, for the reasons given that the normal positions of the signals are different.

The operating power is not one which I will enter upon in this reply at all, as I am dealing rather with the results.

In the matter of the remarks of Mr. Voorhees as to the lines entering New York City from the north observing the block system, I did not make any statement that such lines did not as a principle observe, not only the block system, but the absolute block system. What I inferred was, and I think I made it clear in my statement, that on Columbia Day, which is somewhat equivalent to our Derby Day or Oxford and Cambridge Boat Race Day, where the traffic is abnormal, that it is almost impossible to conduct the traffic on the absolute block system, and I stated that I was almost certain that such lines suspended the absolute block system and used the permissive for that day. With the absolute block only one train can be in one section at one time, and it is doubtful whether the traffic could have been conducted throughout the day with that limitation.

In answer to Mr. G. R. Hardy, the information at Waterloo Junction is not conveyed by the engine-men to the signal-men as to what the signal-men are to do. The English practice undoubtedly takes advantage of introducing engine control from one standpoint over all the business of switching or work done on the track controlled by interlocking apparatus. What is done at Waterloo, which is condemned by the writer, but must be done for want of space, is fly-shunting; then there must be some communication between the switchman and the man in the box. The engine-man or driver has nothing to do with the matter at all. Where fly-shunting is authorized, ground pointsmen are employed, and indication must be given by them at the right moment to the signal-man when he is to move over his switches to allow the engine to go down one road and the cars down another, or *vice versa*.

I would only remark that nothing has been done at any large station in America that has not been previously executed in Great Britain, and if fly-shunting is introduced in America I should like to see the system that would control it from a signal box irrespective of individuals on the ground to give notice of the time when the switches should be reversed for the purposes of fly-shunting. This is only another case of where automaticity is not desirable or even possible.

In the matter of using in-going tracks at Waterloo for opposite movements, no amount of interlocking gives any right to shunt on a line in an opposite direction to which the line is intended to run, and it is only right that unusual and independent appliances should be

given to the signal-man for a movement in the wrong direction on a road that is within the control of the section from which such authority is given or such movement takes place. No amount or combination of well-expressed rules would prevent an accident if drivers are allowed to perform wrong-road shunts without any limit to the extent of such shunts. I am certain that these remarks made by the gentlemen addressing them have been made from a want of knowledge of the particular subject.

In this matter, I quite agree with the suggestion made by Mr. Henry Johnson, and in fact they are identical with the suggestions I made to the Southwestern Company after the Kingston accident; I even went further, and suggested that between each block section there should be a derailing switch which would turn a train which happened to be running on the wrong road off the road. This did not appear to find favor with the permanent-way engineers, and the matter was therefore allowed to drop. It of course becomes a serious question to turn a train off the road, especially if it should be going at a high speed; and as the accidents are not very frequent from the cause cited, it was thought desirable to simply provide a wrong-road stop signal.

I am obliged for Mr. Henry Johnson's contribution to this discussion, and I regret he was not present at the meeting in New York. It gives me additional pleasure in receiving any communications from Mr. Henry Johnson, as I was once his colleague and received many valuable suggestions and instructions from him when we were both on an important English railway together.

It is, however, with some degree of diffidence that I entirely disagree with his remarks in reference to the statement that "Quite a number of blades might have been saved, and the system simplified, by the use of large and distinct indicators for the several routes from any one track, instead of the use of bracketed signals" (at Waterloo).

Mr. Johnson no doubt refers to the system adopted in this country for many years by Messrs. Saxby & Farmer, which finds its largest illustration in the signaling of London Bridge Terminus of the London, Brighton and South Coast Railway.

It will be obvious to any signal engineer who carefully compares a diagram of that station with the Waterloo diagram, that the principle involved in the Waterloo scheme is that one lever operates, in certain cases, several signal arms and outward indications, all indicating a

specific and distinct movement, special locking being employed for that purpose; whereas, in London Bridge the very opposite is the case, several levers being employed, for the purpose of saving locking, for operating one and the same signal arm. As stated in my paper, an immense saving of levers and apparatus might have been effected at London Bridge and all the large termini if the principle carried out at Waterloo was adopted there.

The large and distinct indicators mentioned by Mr. Johnson have a light reflected on to them by a lamp which at night shows a number on the indicator. This, I maintain, is not so satisfactory as giving a separate and distinct signal by night, by illumination; moreover, all reasonable assistance should be given to drivers where there is a multitude of roads, like at Waterloo, as to which road he is to go out upon and which road he is to enter upon, and I certainly consider that, especially going out of the station, the same signal should not be given for a passenger movement, which would be an authority to proceed straight away into the next section and proceed on its journey, as would be given to an engine which is shunting a few yards ahead, not going out of the section, possibly having to be shunted back into the engine-shed or on to a turn-table. Only those who have to work such big yards, from a traffic point of view, know the assistance which is given by the ample signaling arrangements at Waterloo.

Mr. Johnson is wrong when he supposes that I commend the system which involved the accident at Kingston; it was the want of such a system that involved the accident. There was no wrong road signal at Kingston; moreover, the switch points were not arranged for correct working with the disc signal, and this should be the case in all movements through cross-over roads or shunt-back movements from main line into sidings. It is infinitely more necessary to detect a trailing point on the main line which is set in the facing direction for a shunting movement than it is to detect for a facing switch point at a junction. The switch points at a junction lying to the wrong road would not lead to two trains meeting each other in opposite directions; that is to say, there would be no wrong-road working, but a switch point at a cross-over road, in the event of a shunt-back movement failing to work, the signal being lowered and the train proceeding, such train would go in the wrong direction on the main line, as it did at Kingston.

Briefly, I may say that I do not consider that wrong-road signals, except at terminal stations, should be given at all. Better to let the instructions be special from the signal operator to the engine-man, or from the station-master or whoever is in control of the section.

With reference to the remarks of Mr. Tratman, it is obvious to all who know the working of railways in this country that the adoption of a standard system does not imply absence of competition ; it would tend rather to the reverse, for, as I have previously stated, what the Board of Trade asks for in this country are results, the means employed, of course, being subject to their inspection and approval.

There are five signal companies in England who are doing a large business, and who all have their specialties, but this does not refer to the case of the lock and block, as at the present moment there is only one signal company that is offering to the public a suitable lock and block system, in addition to Mr. W. R. Sykes, Sr., who runs his own lock and block system in England.

The space at my disposal is too limited to enter into the question as to the requirements for automatically placing torpedoes on the rails while the signal is at "danger." The use of the torpedo, or what we call the "fog signal," in the United States, seems to be different to its application in England, in the fact that, more especially in tunnels, the torpedoes are in position on the rails when the stop signal is in the "danger" attitude ; so that if no train for a period of 12 months were to run past such signal of danger, provided with such a torpedo, there would be no explosion of the torpedo during the whole of that time. In England, during foggy weather or in certain positions where such appliances are desirable, they are generally applied to the distant signal, and, of course, are exploded in the "danger" position of that signal, as trains are authorized to proceed even when the signal is in this attitude.

Mr. Tratman refers to the introduction of the Mozier system on the New York, Pennsylvania and Ohio as applicable to single-line tracks. I conclude that he infers that this and the Lattig system apply to lines in more or less disadvantageous financial circumstances, over other systems ; although the financial circumstances of any system are, no doubt, desirable, yet it would appear to me to be the first duty of a company or its officers who sanction the adoption of these appliances, to consider the best results to be obtained with reference to the safety

of the traveling public rather than financial considerations. It is, no doubt, possible to get a cheap and a nasty system ; on the other hand, it is, no doubt, possible to get a thoroughly good and reliable system, giving a greater maximum safety, even although it may cost more; and no doubt the latter is that which is desirable.

With the Lattig system, promoted by the National Switch and Signal Company, of Easton, Pa., I would remark that the object set out in the invention is the replacing of the rear signal to "danger" by the passage of a train, and by that means it is considered a block system is established.

A description of this system appeared in the *Engineering News* of January 12th, 1893. I would remark in connection with this that in looking over the description of this invention there are certain features which I think would not commend themselves for general adoption. The first objection is, that if the balance lever on the post is pulled sharply over, the lever in the special apparatus on the post, which acts as an armature, is liable to be wrenched away from the magnet, owing to the sudden jar on the bevel-shaped piece. The rigidity necessary to operate the arm when it should be operated depends upon the magnet holding the before-described lever in position, and, therefore, the force needed to operate the arm is acting to thrust aside the lever as described, which, if thrust aside, the arm would not operate to the "safety" attitude. This objection is not only liable, but has taken place in similar slot arrangements designed in England for similar purposes.

The second objection is, that it has been found next to impossible, at least in Great Britain, to use a track circuit, and I would venture to remark that track circuits in the United States are hardly as correct in working as railway officials would like to see them. Thirdly, the current in the Lattig invention is always on, the batteries requiring much more attention than if only occasionally used, and there is a great liability in them to run down unknown to the attendants, and the line be blocked, certainly automatically.

This and other systems have been called lock and block systems, but the great feature in a lock and block system is the means of releasing the instrument in the block section, if the train does not go beyond the said section; that is to say, that supposing there are three sections, *A*, *B* and *C*; a train has arrived at *B* and is shunted into the

siding at *B*; now where, in the systems I have pointed out, Lattig and Mozier, or any other systems (except the Sykes, Sr., or the Sykes, Jr., and O'Donnell), does the release come in? Even in the Sykes, Sr., in England, the release takes place, or what we would call "cancellation," takes place by means of a key, and although I should be extremely sorry to differ in any way from Mr. Voorhees, yet I see, in answer to a question put by myself, that he replied, "We do not permit a man to do that under any circumstances. We don't allow him to unlock himself." I have before me a photograph of the instructions for working the Sykes system on the New York Central and Hudson River Railroad, Harlem Division, signed by Mr. J. M. Toucey, and I see that under Rule 10 it says: "Unlock me; train has gone on siding and switch to main line is closed. Repeat 10 to sender; if unanswered by 2, plunge." The meaning of that is that the operator at *B* has put the train into the siding, has put back his switch points to the normal position, and he goes through a false movement to unlock his instrument in order that he may plunge to *A* to release *A* to send a second train. I am not aware of any system of automatic releasing used in the United States to obviate the necessity for cancellation or the use of a key, but if there is such a system, then my remarks do not take effect.

With the Lattig system, which in this respect is no better and no worse than every other system that is known to me, even including the Sykes, Sr., system (except the Sykes, Jr., and O'Donnell system, which is a recent invention), all "train in error" signals or all means of delaying the despatch of a train previously sent from the rear section is effected by key, button or false movement. The reason of this is that with all the instruments known, with the exception named, even with the well-known Sykes system, the starting or sectional signal in the section must be in the "danger" position, or, at all events, the operating lever back in its normal position in the locking frame, before the signal-man or operator can plunge to release the section in the rear to allow a train to proceed. It is customary when the operator receives information that the train is coming to request sanction of the section in advance, and when such sanction is given he lowers his starting signal before the train actually gets into his station, consequently if this train does not proceed to the next section, but is shunted into a siding, he is locked up and cannot plunge to accept another train from the rear until he has put his own

starting signal to "danger," which action releases his instrument and allows him to accept a second train from the rear; but, having put his own starting signal to "danger" for the reasons given, he cannot lower it again until *C*, the section in advance, has released him or given him sanction, and *C* having already given him sanction once cannot release himself to give a second sanction until he, *C*, releases his instrument by going through a false movement, as though a train were passing through. This description refers to the Sykes system, where treadles are not provided. Where a treadle is provided with the Sikes system, the same objection of cancellation takes place, or what we term cancellation of signal takes place; but, instead of as previously described, the action is as follows:

B accepts a train from *A* and concludes it is going into *C*, *B* lowers his starting signal; the train arrives at *B*, and it is decided that it shall not go to *C*, but be shunted into a siding at *B*. A treadle is fixed a suitable distance ahead of the sectional signal at *B*, in fact, where a treadle is used for block purposes, it is fixed in advance of all sectional signals; the operation of the treadle is that when the starting signal, say at *B*, is lowered, sanction having been given by *C*, *B's* treadle is placed in operation; when *B's* starting or sectional signal is worked over, it becomes locked in this position, that is to say, the worked position, and is held locked in that position, under ordinary circumstances, until the train has reached the treadle, which releases it and allows it to be placed normal. If, therefore, the train is not to proceed to *C*, but is shunted into the siding, *B's* starting signal is locked in its over position, and it must be returned in order that he may plunge to get a second train from *A*; and in order that it may be put back to allow the instrument to be plunged, it must be released, and this is done by the pressure of a button, or, in other words, by "cancellation." In this case, also, *C* having once plunged to give sanction to *B* to send a train, his instrument is locked, and it must be released in order that *B's* starting signal may be lowered. To obtain this release a false movement must be gone through to obtain the cancellation of the previous signal, in order that fresh sanction may be given to *B* to forward a train.

In all of these systems it will be observed that the very wrong principle of giving authority and allowing it to be cancelled at will by the signal-man is employed. It is obvious that no true definite safety is

obtained by means of this privilege of cancellation, because, by a stretch of imagination, although it may actually occur, a signal-man may cancel his signals a sufficient number of times to have the whole of the section in the rear blocked by trains.

Although these peculiarities of lock and block system are known to railway managers, it is doubtful whether the traveling public, who place such implicit faith in the union of the lock and block systems, are aware of these characteristics.

It therefore occurred to me, in conjunction with Mr. W. R. Sykes, Jr., as to whether the radical disadvantages of these systems could not be obviated by devising a method by which, in lieu of the cancellation of signals, the suspension of the operation be employed.

This we claim to have successfully accomplished, with the result that, assuming three sections, *A*, *B*, and *C*, if a train arrives at *B* and it has been previously signaled on to *C*, and *B* decides that it shall not pass his section but go into a siding, the previous sanction obtained from *C* remains operative for any train that may next pass into *C's* section. *B* releases his instrument through the legitimate movement of passing his train either into the siding, on to the other road, or in any position clear of the main line.

Another feature which is certainly desirable and which is not obtained in any of the existing systems so far as I am aware, is that, assuming *C* has given sanction to *B* to send a train, and for some reason or other it is undesirable that *C* should receive the train at the particular moment and he wishes to delay it, say for a quarter of an hour, by other systems cancellation takes place by means of a key, or through the movements reversing the sanction; whereas, with our system the operator at *C* reverses his suspension switch, places the starting signal or sectional signal at *B* if it has previously been lowered, to "danger," indicates in the instrument at *B* that he has placed the signal to "danger" by the semaphore arm in the instrument at *B* assuming the "danger" attitude, and also replaces the semaphore arm in his own instrument to the "danger" attitude; now, when the time has elapsed and *C* finds it convenient for the train to come on to his section, he does not need to give any fresh signal, but simply replaces his suspension switch to its normal attitude making operative the sanction he first gave for *B* to send the train. Again, with this system, the result of which is not claimed as novel (but the particular means

of affecting it are claimed as novel), as each train leaves its section it depresses a treadle (if desirable a track circuit may be used, as they are so successful in the United States), which replaces the sectional signal in its rear to "danger," and releases the instrument immediately in its rear, allowing the operator to plunge and accept another train from the rear.

I would remark, in reference to the praise of the electric slot, the signal being automatically set to "danger" by the passing of the train until the train has passed on to the next section, that it has been tried for several years in America, that it has been successfully in operation in connection with all the trains passed out of Waterloo Station (London and Southwestern Railway), which amount to some 800 every 24 hours, since May, 1892, and it was carried out by Mr. W. R. Sykes, Sr.

I fully agree that the best results can only be obtained by the union of the lock and block system, but this union must be of the latest and best type.

I need only take the opinions expressed in the course of this discussion as an answer to the automatic system of signaling being the best system for the States or any other country. It is considered essential on all hands that a thorough lock and block system, whether automatic, electric, pneumatic, or manual, is desirable as a result. We have Mr. Voorhees' words set forth in this discussion, that he had to make it a rule that engineers could pass block signals at "danger," provided they waited a time interval. This refers to the pneumatic block plant put in between Mott Haven and Woodlawn. He says: "I do not think it possible to work any automatic signal except under such a rule. It is under that view that the New York Central and Hudson River Railroad has gone into the Sykes system from New York to Buffalo, which is now under contract."

In the matter of illuminated signals for night, that is to say, means employed for illuminating the arm, I do not think that this would be considered as practical by railroad men generally. Many devices tried in England I can only class as failures. The great difficulty is to give a suitable and correct view of the distant signal in advance, and I believe it is generally said that all the methods of illuminating the arm, in preference to the usual system of lamp, have not given a greater assistance of correct sight beyond 120 yards.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XXVIII.—May, 1893.)

THE DETROIT UNION DEPOT VIADUCT.

By J. W. SCHAUB, M. Am. Soc. C. E.

In the year 1890 a company was incorporated under the laws of the State of Michigan, known as the "Fourth Street Union Depot Company," of Detroit, Mich. It was composed of four prominent railroad companies, namely, the Wabash, the Canadian Pacific, the Flint and Père Marquette, and the Detroit, Lansing and Northern. All of these railroads were then entering the city of Detroit over various lines, with widely separated termini; and in order to facilitate the interchange of business, and for other reasons, they determined to build a Union Depot in the heart of the city, with elevated approaches, similar to the Broad Street Station in Philadelphia. In order to accomplish this it was necessary to build a three-track viaduct about 4 000 ft. long through River Street. After a great deal of litigation, the route was finally secured, and the locations for the columns of the viaduct were fixed. Thereupon, Mr. C. H. Ellis, the Chief Engineer for the Depot company, prepared the specifications and invited tenders.

In January, 1891, the contract for the viaduct was let to the Detroit Bridge and Iron Works, the work to be completed in eight months. The writer, as the engineer for the Detroit Bridge and Iron

Works at that time, was called upon to design the superstructure, and he will confine himself in this paper to describing only that portion of the work. The locations for the columns were fixed by Mr. Ellis, who also designed the foundations and footings for the masonry piers.

Superstructure.—The live load assumed for each track consists of two 104-ton engines (Cooper's Extra Heavy "Class A"), followed by 3 000 lbs. per linear foot.

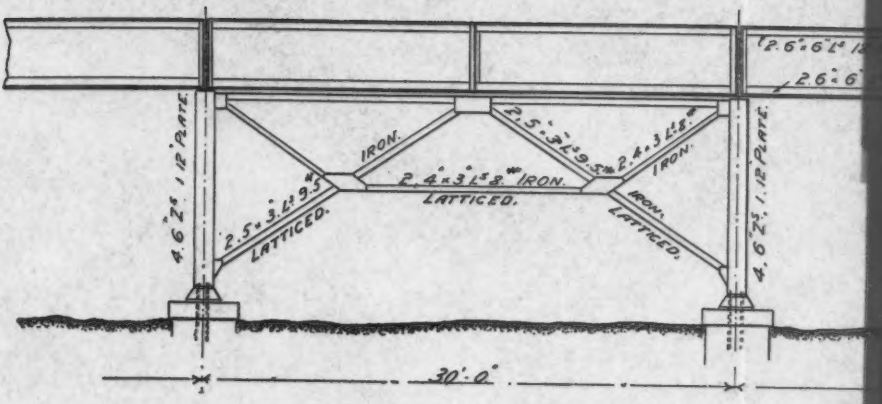
To provide against the effect of the longitudinal force due to friction between the wheels and the rails, two trains, each weighing 3 000 lbs. per linear foot, were assumed to be moving in the same direction upon the outside tracks. The maximum coefficient of friction between the wheels and the rails was assumed at one-fifth. To resist this force, a longitudinal bracing is provided for between the columns. In some cases this bracing goes to the ground; generally, however, it is taken up by means of flexure in the columns. No account was taken of the "horizontal displacement" of the live load due to friction.

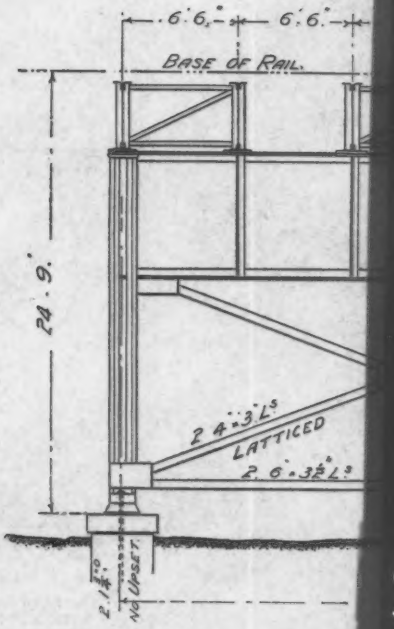
To provide against wind strains and lateral vibrations, a wind force of 750 lbs. per linear foot was assumed. For convenience, this force was assumed to be acting in a horizontal plane passing through the base of the rails. To resist this force, a transverse bracing is provided for, between the columns. In some cases this bracing goes to the ground; generally, however, it does not, and flexure is produced in the columns. The horizontal displacement of both dead and live loads, due to wind, is provided for in proportioning the columns.

In speaking of the horizontal displacement of a load, due to wind or friction, it might be well to explain the conditions under which this takes place. The following demonstration is original, and is so general in its application that the writer thought it worth while to present it in this paper.

Any force in space, whether it be in a vertical, horizontal or inclined plane, which acts upon any structure, must ultimately find its reaction in the ground. The route which it selects, in finding its reaction, will be such that the internal work which this force does in producing strain in the structure will be a minimum.

If a structure, like this viaduct, rests upon immovable masonry piers bedded in the ground, we can, for the time being, assume that these reactions exist at the supports for the columns. If the columns are square-ended and firmly held down to the masonry by means of


2.6"x6"L's 1/2
2.6"x6"
4.6"x2½"x1/2" PLATE.
2.5"x3"L's 9.5#
LATTICED.
IRON.
2.4"x3"L's 8#
2.5"x3"L's 9.5#
2.4"x3"L's 8#
IRON.
IRON.
LATTICED.
4.6"x2½"x1/2" PLATE.
30'-0"


6'6"
6'6"
BASE OF RAIL.
24'9"
2.4"x3"L's
LATTICED
2.6"x3½"L's
2.1½" TO
NO UPSET.

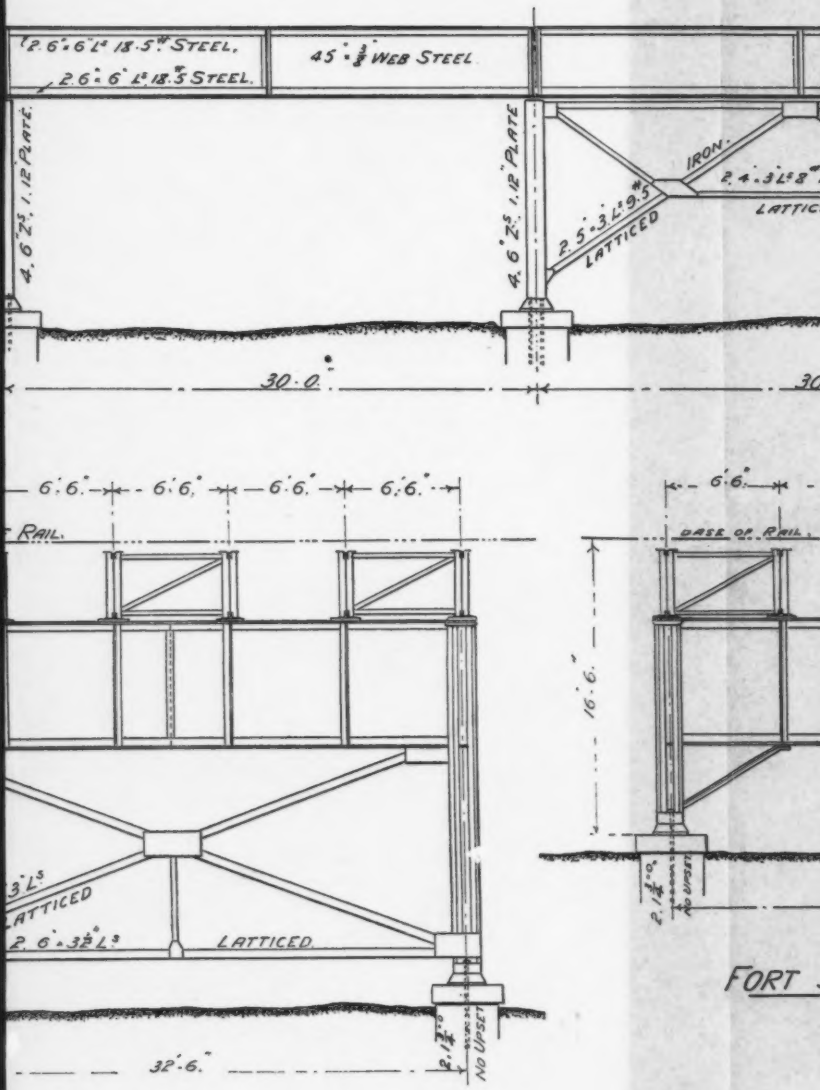
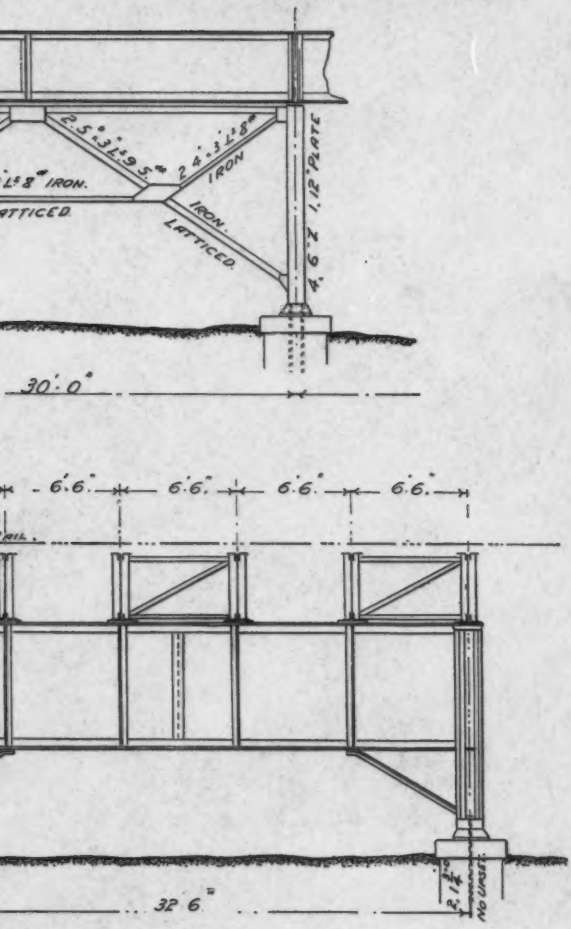
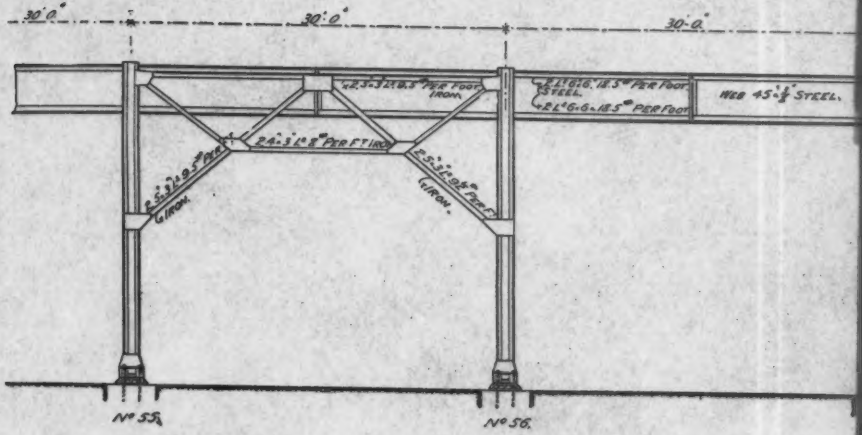

2.6"×6"L^s 18.5^# STEEL.
2.6"×6"L^s 18.5^# STEEL.
45"×⅜" WEB STEEL
4.6"Z^s 1.12" PLATE.
4.6"Z^s 1.12" PLATE
IRON.
2.4"×3"L^s 8^#
LATTIC
2.5"×3"L^s 9.5^#
LATTICED
30'-0"
6'-6"
6'-6"
6'-6"
6'-6"
RAIL.
3"L^s
LATTICED
2.6"×3½"L^s
LATTICED.
32'-6"
2.1½"
NO UPSET
6'-6"
BASE OF RAIL
16'-6"
2.1½"
NO UPSET
FORT

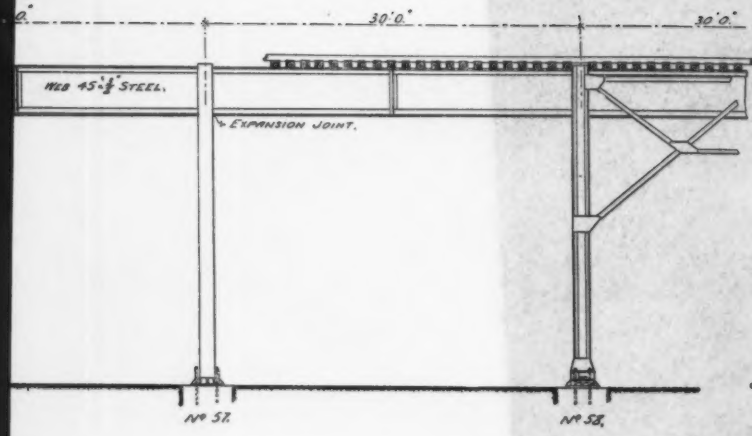
PLATE XLIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 593.
SCHAUB ON DETROIT UNION DEPOT VIADUCT.



PT ST UNION DEPÔT VIADUCT.

Scale.
0 2 4 6 8 10 12 14 16 Feet.


30'0"
30'0"
30'0"
2 L's 3"x3"x10.5" PER FOOT IRON
2 L's 3"x3"x10.5" PER FOOT IRON
2 L's 3"x3"x10.5" PER FOOT IRON


30'0"
30'0"
WEB 45-⅛" STEEL.
EXPANSION JOINT.
Nº 57.
Nº 58.

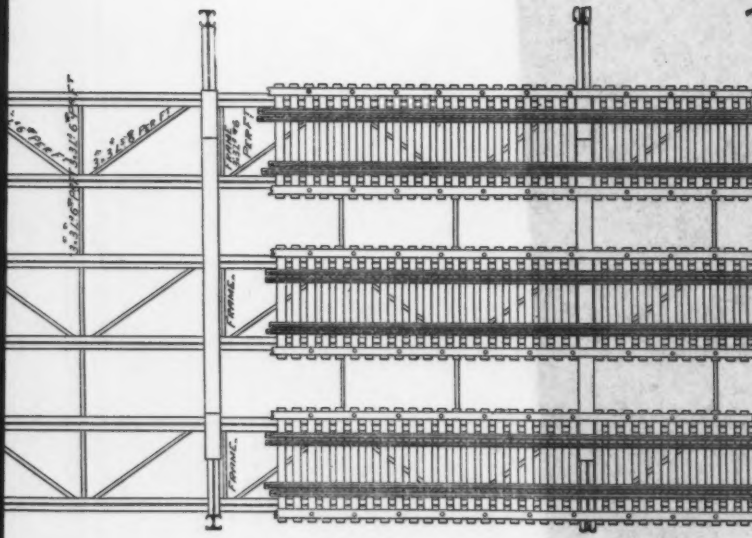


PLATE XLV.
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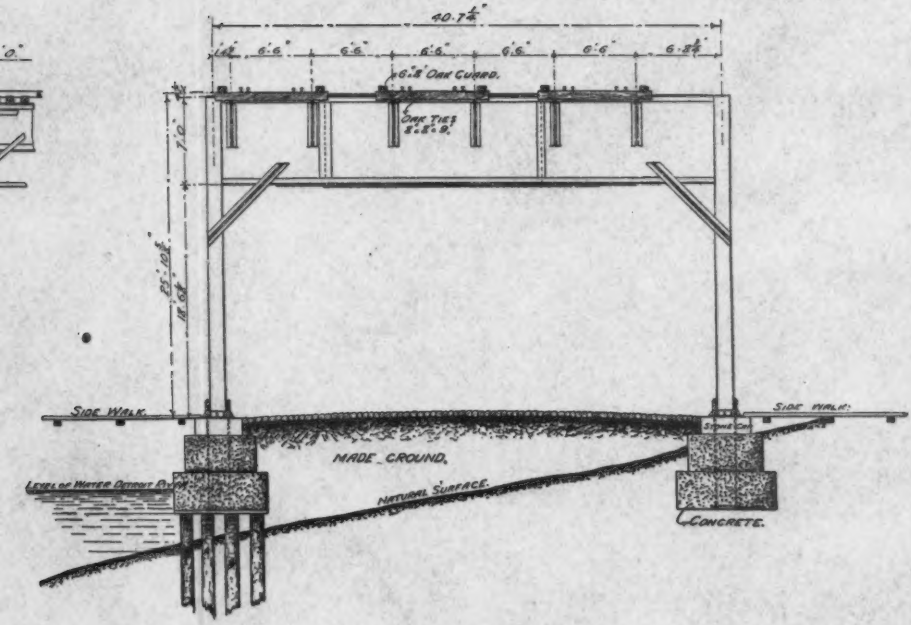
SCHAUB ON DETROIT UNION DEPOT VIADUCT.



Scale

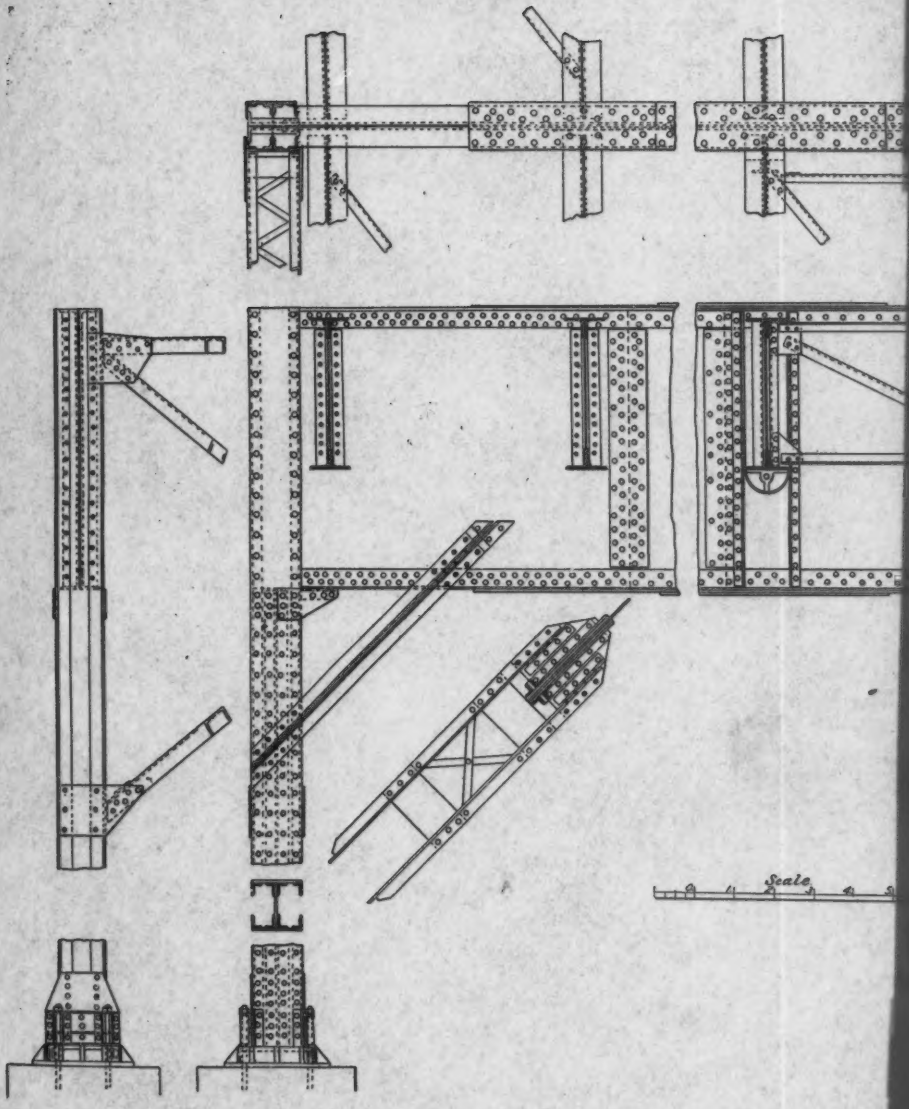

Scale

PLATE XLVI.
TRANS. AM. SOC. CIV. ENGRS.
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SCHAUB ON DETROIT UNION DEPOT VIADUCT.

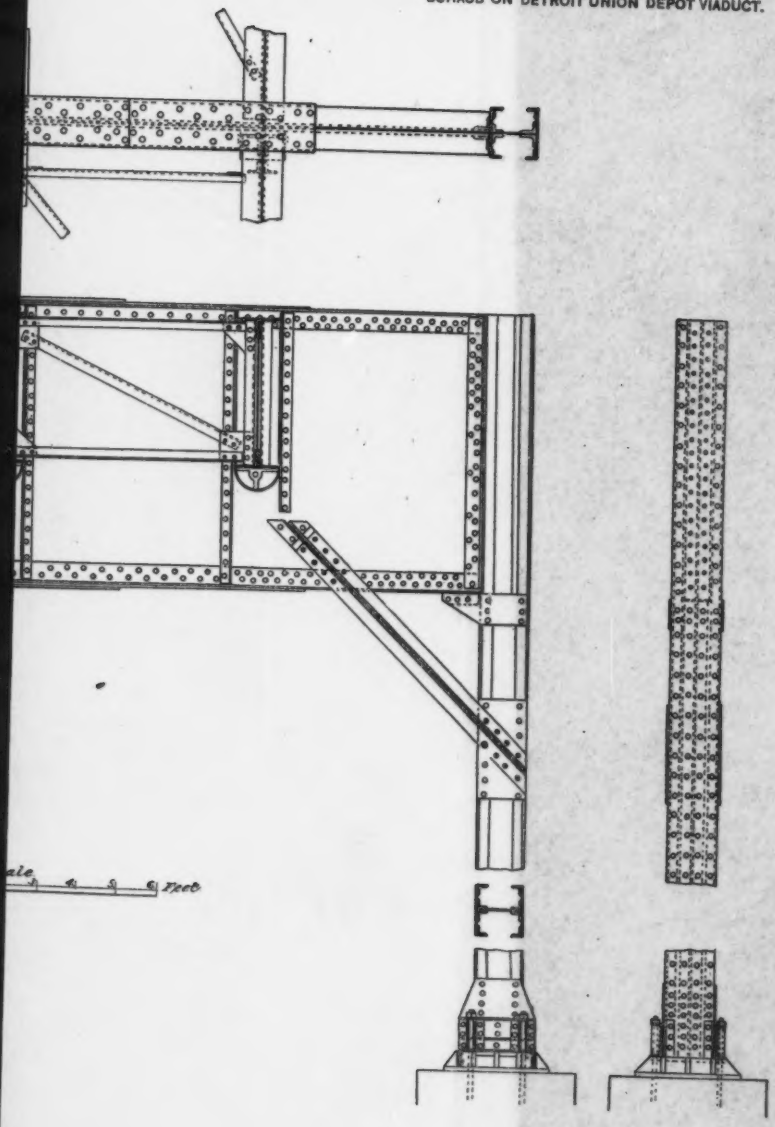
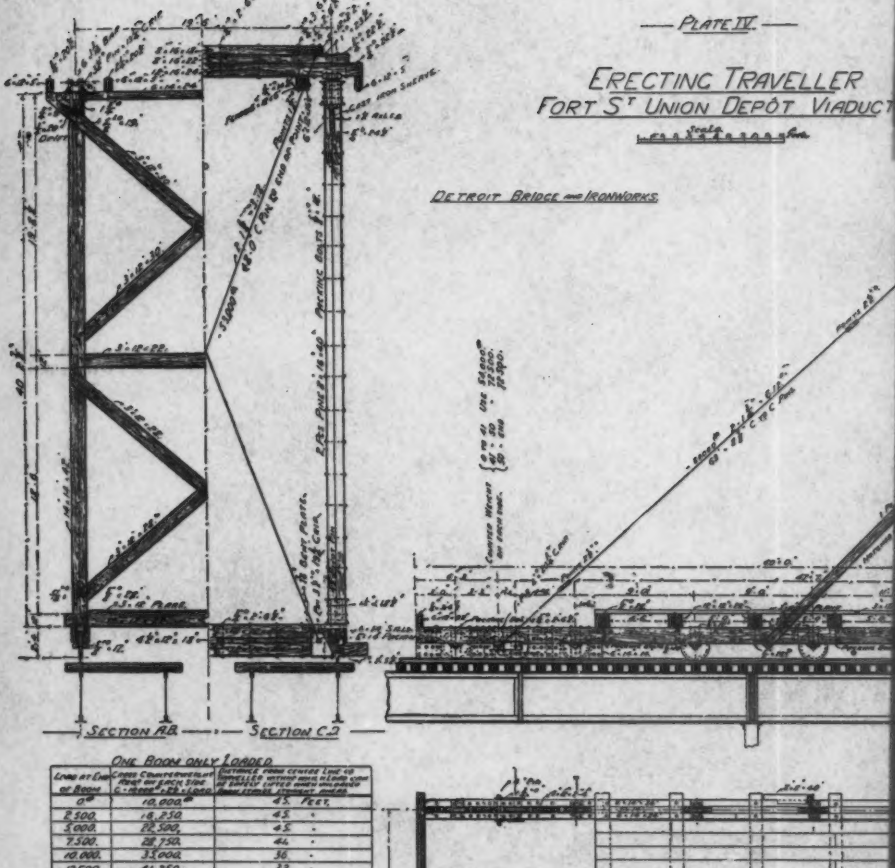


PLATE IV.

ERECTING TRAVELLER
FORT ST UNION DEPOT VIADUCT

DETROIT BRIDGE AND IRONWORKS



ONE BOOM ONLY LOADED

Load at End of Boom	Chord Compression in Top or Each Side C = 10000 × E.R. Load	Distance from Center Line of Travelled Bottom when Load is at End of Boom
0 lbs	10,000 lbs	45 Feet
2,500.	18,250	45 "
5,000.	22,500.	45 "
7,500.	28,750.	44 "
10,000.	35,000.	36 "
12,500.	41,250	32 "
15,000	47,500.	30 "
17,500	53,750.	28 "
20,000.	60,000	26 "
22,500	66,250	24 "
25,000.	72,500.	23 "

BOTH BOOMS LOADED

Load at End of Both Booms	Chord Compression in Top or Each Side C = 10000 × E.R. Load	Distance from Center Line of Travelled Bottom when Load is at End of Booms
25,000 lbs	41,250 lbs	17 Feet
30,000	47,500	" "
35,000	53,750	" "
40,000	60,000	" "
45,000	66,250	" "
50,000	72,500	" "

Note: When it is necessary to handle Loads etc. greater than 45,000 lbs. Load from Forward End of Traveller

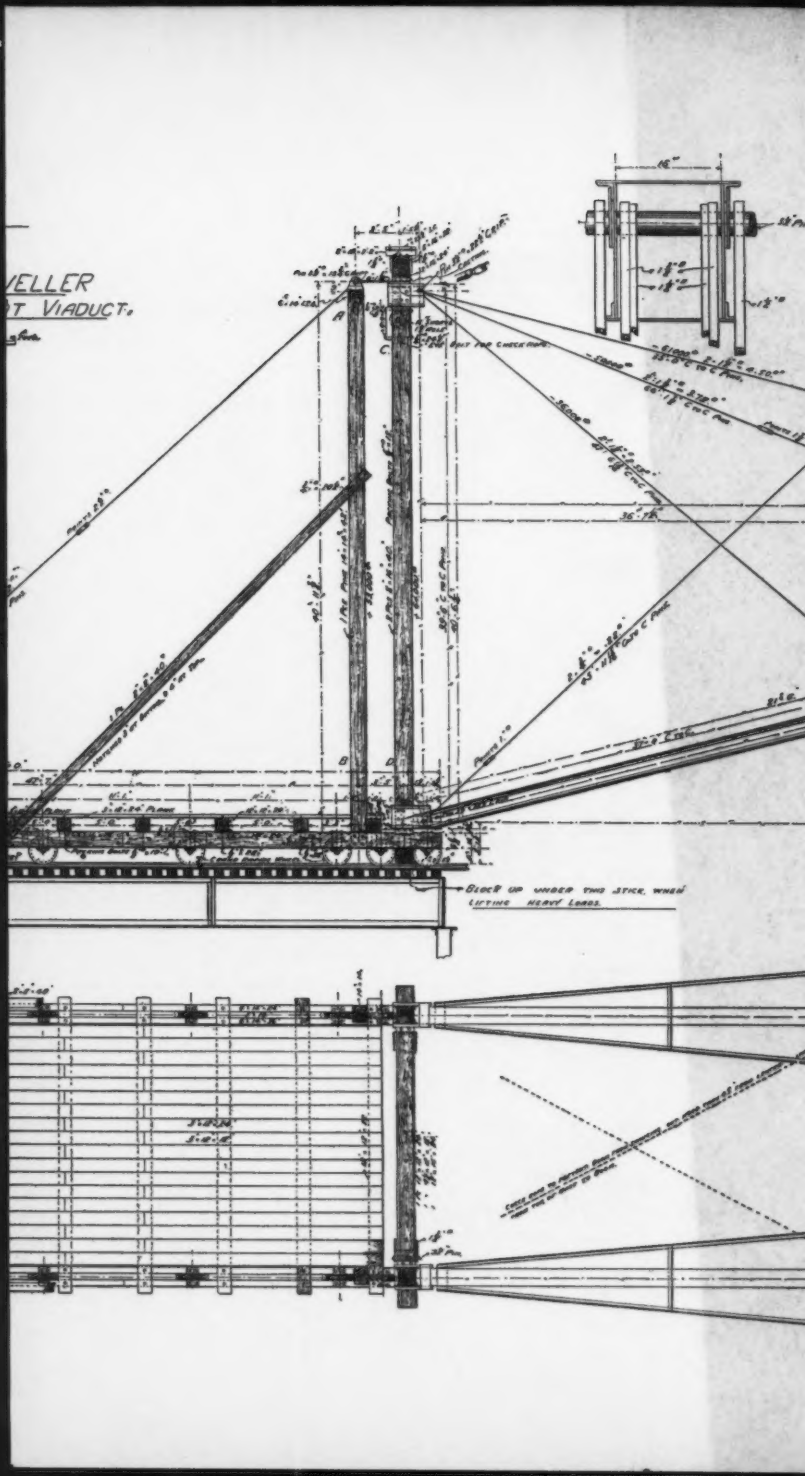

VELLER
T VIADUCT.
BLOCK UP UNDER THIS STICK, WHEN LIFTING HEAVY LOADS.

PLATE XLVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 593.
SCHAUB ON DETROIT UNION DEPOT VIADUCT.

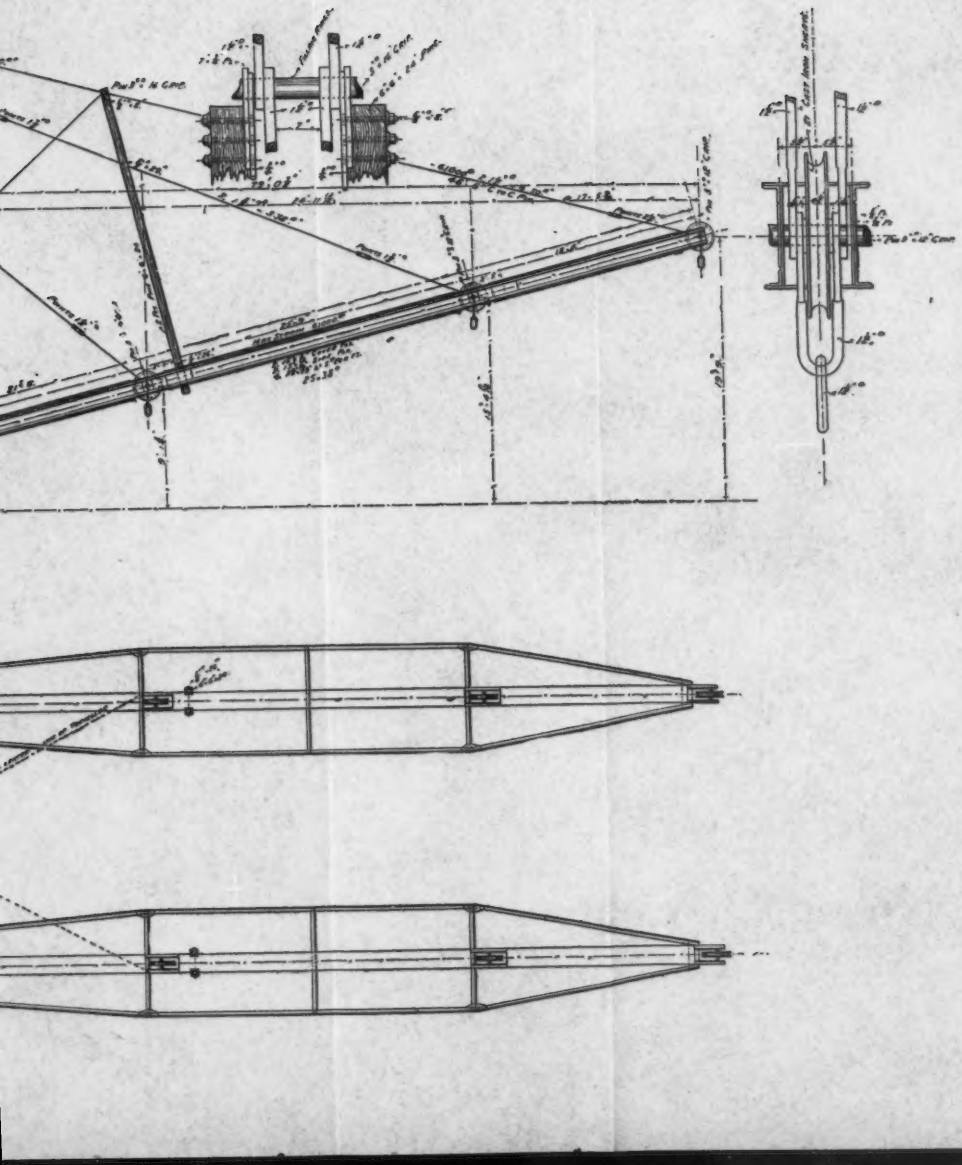
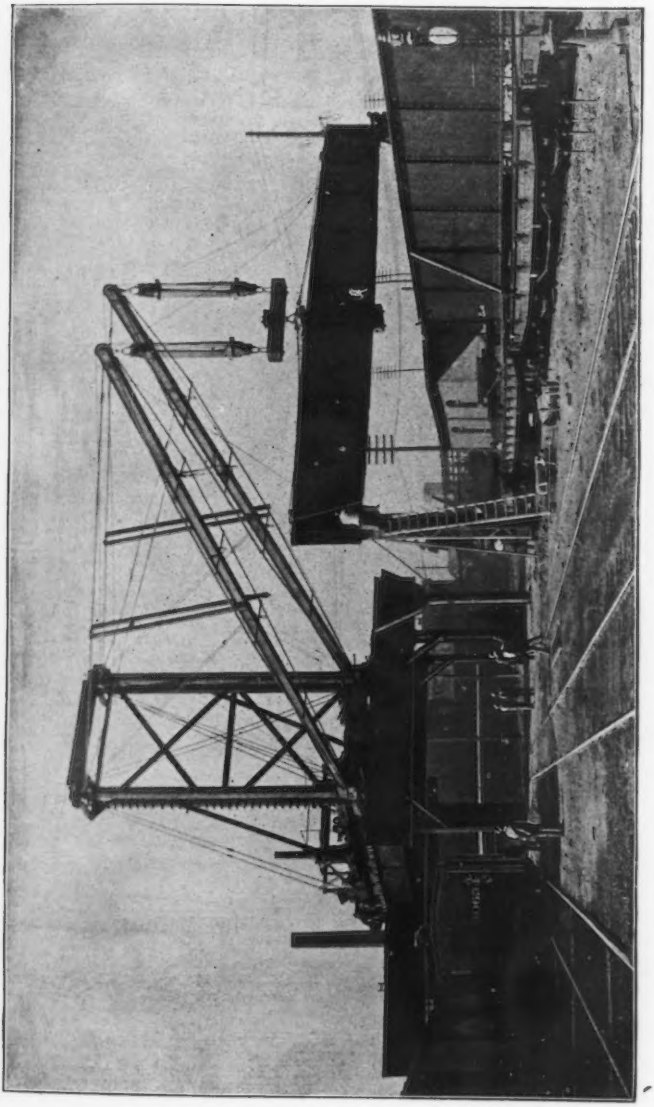
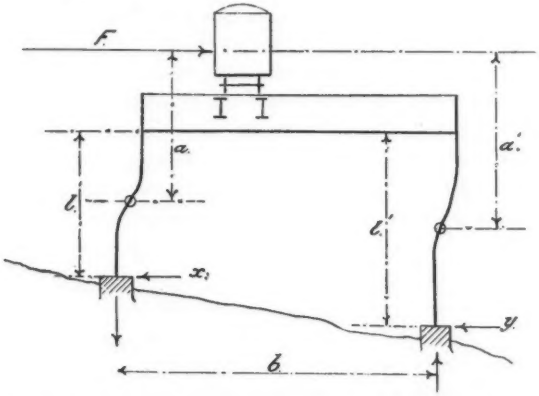


PLATE XLVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 593.
SCHAUB ON DETROIT UNION DEPOT VIADUCT.



anchor rods, so that the columns and the masonry act as a unit, it is evident that the columns themselves can exert reactions against external forces in any direction.

If the external forces be vertical, the reactions will be vertical, without producing any direct bending in the columns. If, however, the external forces be horizontal or inclined, such as those produced by wind or the friction of the wheels on the rails, then the reactions will be both horizontal and vertical, and their resultant must necessarily balance the resultant of external forces. The horizontal reactions are opposed by the resistances of the columns to flexure. The vertical reaction produced by any external force is the result of a couple produced by the horizontal component of the external force and its corresponding reaction.



In the figure, let us assume an external force F acting upon a portion of a structure supported by two columns, whose unsupported lengths are l and l', placed a distance b apart. For convenience, the force F is assumed to be horizontal. The bracing between the columns does not go to the ground, so that the external force F produces direct bending in the columns. As the columns are assumed to be fixed at both ends, their bending will cause them to assume lines of double curvature with points of contra-flexure midway between their supports. Let I and I' represent the moments of inertia of the columns. Let E represent the modulus of elasticity of the material in the columns.

Let x and y represent the horizontal reactions produced by F; then

$$\text{deflection} = \frac{2x\left(\frac{l}{2}\right)^3}{3EI} = \frac{2y\left(\frac{l'}{2}\right)^3}{3EI'} \quad \therefore \frac{x}{y} = \frac{I}{I'} \times \frac{l'^3}{l^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

but $x + y = F \therefore y = F - x$; then equation (1) becomes—

$$\frac{x}{F-x} = \frac{I}{I'} \times \frac{l'^3}{l^3} \quad \therefore x = \frac{F}{1 + \frac{I'\,l^3}{I\,l'^3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Substituting in equation (2) the values for l and l', and assuming values for I and I', we can solve for x and then find y.

The bending moments on the columns are:

$$x \times \frac{l}{2}, \text{ and } y \times \frac{l'}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The vertical reactions produced by F are:

$$+ \text{ and } - \left(\frac{x\,a + y\,a'}{b}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

which represent the horizontal displacement produced by F; inasmuch as they would simply increase and diminish the reactions produced by any purely vertical load, without changing their algebraic sum. Their effect is the same as if the vertical load were displaced horizontally; hence the term horizontal displacement. Here, we have assumed the lengths of the columns to be different. We have also assumed I and I' to be different. When $l = l'$ and $I = I'$, then from equation (2) $x = \frac{F}{2} \therefore y = \frac{F}{2}$. The bending moments (3) become $\frac{F}{2} = \frac{l}{2}$.

The vertical reactions (4) become $+$ and $-\left(\frac{a\,(x+y)}{b}\right) = +$ and $-\left(\frac{F \times a}{b}\right)$. If the construction should be such that $l = o$, which means that the cross-girder is supported at one end on solid masonry, while the other end is supported by the column l', then from equation (2) $x = F \quad \therefore \quad y = o$, which means that the horizontal reaction is entirely taken up by the masonry, and no cross-bending is produced in the remaining column.

We have also from (4) the vertical reactions produced by F $+$ and $-\left(\frac{F \times a}{b}\right)$. As l is now $= o$, a is the vertical height of F above the masonry.

It is apparent that F is assumed here as a transverse wind force acting against cars, the center of pressure being assumed in the center of gravity of the exposed area. The force F might have been assumed as a longitudinal force due to friction, acting through the center of gravity of the moving load, in which case it would produce bending on the columns in a longitudinal plane.

In proportioning the columns, the combined stresses resulting from direct loading, displacement due to wind, and cross-bending were provided for; but in no case were the stresses resulting from wind and friction assumed to occur at the same time.

The material in the superstructure is steel, excepting the bracing and the anchorages, which are iron. The bearing plates for the columns on the masonry are cast iron. The steel used was specified as "medium steel," excepting for rivets, where "soft steel" was specified. The requirements of the specifications were practically the same as given for "medium steel" and "soft steel" in Carnegie's "Hand Book for 1892." No shape iron or steel weighing less than 6 lbs. per linear foot was used, nor any web plates less than $\frac{3}{8}$ in. thick, nor any other metal less than $\frac{5}{16}$ in. thick. All holes in steel were punched and reamed, and all sheared edges of web plates were planed. The permissible working stresses for steel in pounds per square inch were as follows:

For tension flanges of longitudinal girders and cross-girders (net) 10 000. The compression flanges were made to have the same gross area as the tension flanges.

For columns whose length exceeds 100 times the least radius of gyration, $P = \dfrac{12\,000}{1 + \dfrac{L^2}{40\,000\,R^2}}$; for short columns $P = 9\,600$ lbs. per square inch. In no case, however, do the stresses from direct loading, combined with the stresses resulting from wind or friction, in any column exceed 12 000 lbs. fiber strain per square inch on the outer fibers.

For shearing on rivets.....	9 000 lbs.
For bearing on rivets.....	14 000 "

For field or hand-driven rivets, only two-thirds of the above values were allowed. In place of the field rivets, bolts were used. These bolts were cut from cold-rolled steel shafting, $\frac{15}{16}$ in. in diameter, or

the same as the diameter of the last reamer used in reaming the holes. The bolts were threaded at each end, and provided with a nut and washer at each end. As they were perfectly smooth and round, they were equivalent to turned steel bolts, and their values were taken the same as given for field rivets.

The general character of the details of the superstructure is shown by the accompanying plans. The salient features in the design are:

First.—The absence of all adjustable members, all bracing being riveted.

Second.—The form of expansion joint used for the longitudinal girders.

Third.—The connections for anchor rods to columns.

Fourth.—The use of cast bearing plates for distributing the pressure on the masonry.

Fifth.—The form of the longitudinal bracing.

Plate XLIV shows the general design for longitudinal and transverse bracing where no clearance is required under the structure and the bracing is permitted to go to the feet of the columns.

Plate XLV shows the general design for bracing where a clearance of 14 ft. is required over the streets.

Plate XLVI shows the details for columns and cross-girders, also; the details for the expansion joint used. Expansion joints are provided in every 90 ft. longitudinally.

Plate XLVII shows the general design of the traveler used in erecting the iron-work (see, also, view of traveler, Plate XLVIII). The conditions governing the erection of this viaduct precluded the use of a through traveler, so that a deck traveler was used. The heaviest single piece handled by this traveler was a cross-girder weighing 50 000 lbs. at the end of the booms reaching out 80 ft. In order to handle heavy weights at such a distance, the rear end of the traveler was counter-weighted with 75 tons of pig iron.

In erecting this work no special difficulties were encountered beyond those that were expected and provided for. In some cases it was found necessary to set the cast bearing plates on a thin layer of cement, to bring them to a level. This was owing to improper setting of the coping stones, or imperfect finishing of the castings, or both these causes combined. This difficulty is commonly met with in all kinds of work where accuracy of bearing on masonry is required. The writer

does not recommend the use of thin layers of cement for shims. The cement does not make a bond with the coping stone, and soon crumbles and wears away at the edges of the casting.

In the Testing Laboratory of Washington University at St. Louis, plaster of paris is used for shims under stone columns while being tested. This method of leveling up bearings on small areas of masonry seems to promise well. The plaster, even in thin layers, makes a bond with the stone and sets rapidly. If it becomes necessary to retard the setting, a little lime can be added to the mixture.

The use of sheet lead is questionable in such cases, especially where the surfaces of bearing plates are unbroken by recesses. Ordinarily the working pressures on the bearing plates are not sufficient to cause the lead to flow. The coping stones might be dressed to a true level, and the bearings planed exactly square; but even then, when the columns are placed in position, it is not unusual to find that they are not plumb. Under such conditions some simple method of remedying the evil must be found, so as not to delay the work. The question is an important one, especially where the direct bending in the columns is such a large factor.

DISCUSSION.

F. COLLINGWOOD, M. Am. Soc. C. E.—There is one subject spoken of by the writer, that is, the use of plaster for leveling up bearing plates, which is a very important one. It has been found in testing cubical blocks of stone, where it is desirable to get an absolute bearing to distribute the pressure uniformly, that there is nothing so good as plaster of paris. That was the experience at the Watertown Arsenal. They tried thin layers of wood, and the result was that under heavy pressure the wood itself seemed to exert a force in a direction across the fibers, tending to cause rupture in a direction parallel with the fibers rather than the other. There was nothing which gave so uniform results as plaster of paris. When used and given time to set, the results were more nearly comparable than from the use of any other material.

CHARLES MACDONALD, M. Am. Soc. C. E.—There is so much of it that looks familiar to us, that to many who have been all over this ground before it seems like A B C; but if any point suggests itself, we should be only too glad to hear it.

Do I understand correctly that there is a circular railroad, something of this character, around Berlin?

W. G. TRIEST, Jun. Am. Soc. C. E.—The road which is referred to is the Berliner Stadtbahn, an elevated structure which crosses the city from east to west in a sinuous line, not following any streets, but cutting through the blocks. Outside of the city limits, beyond the junction depots, its tracks slope down and connect with the north and south belt lines which completely surround Berlin, and with the eleven railroads which run into that city. The strategic desirability of connecting effectually the eastern and western railroads led originally to its construction, but the Stadtbahn has now become an indispensable factor in the conveyance of local traffic. It is a four-track arched viaduct, with embankments at each end as approaches. Of the tracks, two are reserved for local traffic, while the other two are traversed by the suburban and through trains of the connecting railroads. The length of the viaduct between the two termini, Schlesischer Bahnhof and Charlottenburg, is 39 850 ft. The radii of the curves vary between 980 and 1 640 ft. The grades are from 0.2 to 0.8 per cent. Of the entire structure, 26 120 ft. are built as arched viaduct, and 5 980 ft., including street crossings and iron bridges, have iron superstructure. The rest consists of ordinary embankment and embankment between retaining walls. The width of the viaduct is 51 ft. from face to face. This width accommodates four tracks, but does not leave room enough between tracks to operate and repair the road conveniently.

The arches are generally of 50 ft. span, 10 ft. rise and curved to a radius of 29 ft. The ground plan is mostly rectangular, and oblique arches were resorted to in a few isolated cases only. The arches have on top a course of hollow brickwork carefully arranged for drainage and air circulation. The drainage is carried off through the center of the piers. All arched masonry is covered with a water-proof layer of felt and asphaltum. Above the arches the viaduct is finished with a low retaining wall on either side, which confines the materials of the roadbed and supports the coping and railing. The masonry of the foundations and of the piers and arches consists of brick laid in hydraulic cement. The masonry is plain, with little attempt at ornamentation, and only at street crossings or where the viaduct runs parallel to a street for some distance is the architectural appearance of the structure improved by stone trimmings, cornices and recessing of the masonry. The foundations did not present particular difficulties. Good sharp sand was found within a few feet of the surface, excepting in a few exceptional locations which were originally old water-courses, and where the sharp sand was encountered at greater and irregular depths with overlying strata of peat. The viaduct structure is founded either on masonry direct, on masonry or concrete between sheet piling, or on piles. There are 65 street crossings which, on account of

the limited head room, were mostly constructed as iron bridges on massive masonry abutments. Where it was possible, arch bridges were used, but beam bridges predominate. The length of span of the latter varies from 25 to 50 ft., and most of them are continuous plate girders, resting on four supports. The floor of the bridges consists of galvanized buckle-plates resting upon a grating of angles. The convex side of the plates is turned downward, and is perforated by a hole in its center which connects with a system of wrought-iron leaders. The plates are ballasted, and the rails and ties are bedded in gravel. All street crossings are provided with sidewalks and hand railings.

The River Spree is crossed three times, the Landwehr Canal twice, and a canal basin once. Of these six bridges two are built of stone, and the others have iron superstructure on stone piers. One of the Spree crossings, which is on a curve of 980 ft. radius, has two openings of 59 ft. measured at right angles; the arches are each built of 11 concentric rings of masonry, eight of which carry the four tracks. The other stone bridge crosses the canal at right angles and has one opening of 80 ft.; of the four iron bridges, one is a two-hinged arch, crossing the Spree with a clear opening of 158 ft. The bridge over the canal-basin is the largest one on the line, with five openings of about 100 ft. each. Each track is carried by a pair of single-web system lattice girders, with floor beams at each panel point. The stringers are trough-shaped and filled with gravel in which the sleepers are bedded. The bridge over the Spree at Bellevue crosses the river at an angle of 45°. It has three openings of 56 ft. in the clear, and the superstructure consists of four main lattice girders, one under the center of each of the four tracks. The bridge over the Kupfergraben has two spans of 85 ft. each. There are two two-hinged plate girder arches, 8.2 ft. deep for each track, carrying the tracks on iron floor beams.

The Stadtbahn has eight stations besides the two terminal depots. Out of the 10 depots, five are used for local traffic only. The stations have two stories, of which the lower, on the street level, contains the ticket offices, waiting rooms, buffets, etc. Wide staircases give access to the upper platform, which is on a level with the road and covered. The immense arched hall at the Friedrich-Strasse station is worth mentioning; it is 230 ft. wide and 492 ft. long. Those at Alexander Platz and at the Schlesischer Bahnhof are also very large.

The total first cost of the Berliner Stadtbahn is $8 377 400 for the acquirement of right of way, and $9 482 900 for construction. The building of the railroad began in the fall of 1875. The road was opened for traffic in May, 1882.

C. E. Moore, M. Am. Soc. C. E.—From the inception of the enterprise until the plans were completed the writer was in the service of the Fort Street Union Depot Company as Principal Assistant Engineer,

Mr. C. H. Ellis being the Chief Engineer. The time of the Chief Engineer being to a great extent occupied by the litigation incidental to construction in a large city, and in general plans and superintendence, the calculation and detail work of the viaduct devolved correspondingly upon the writer. Possibly a few words from the point of view of the company's engineers may be of interest.

The conditions imposed generally fixed the location and size of columns, clearance under cross-girders and bracing, and under longitudinal bracing.

Economy generally demanded the greatest depth of cross-girder, and the largest column which the conditions allowed. Only for a short distance on railroad property could the design be made for economy only. The result was necessarily great irregularity, very few bents being duplicates one of another.

To satisfy all the varying conditions and to get the matter in shape for proposals, plans were made embodying the general features of the design, before submitting to the bridge companies.

The length and depth of all girders were determined by conditions as above noted. The position of longitudinal girders was fixed, it being necessary to place them in a great variety of positions with reference to the columns. In many cases the outside girder was supported by an overhang of the cross-girder projecting beyond the column.

The question of longitudinal thrust was taken up, and, after considerable study of the problem as affected by the circumstances of this particular case, it was decided to make each section between expansion joints self-supporting as regards this thrust from two trains, and not to rely upon the track connections, etc., to carry it from one section to another.

The method of treatment for columns was fixed upon, anchoring the base and thus dividing the length as regards flexure, and calculations were made for each column. The weight of the structure was calculated and combined with the maximum live load, to ascertain the maximum load on each column base.

The plans were then submitted to the bridge companies, leaving the details for design by the contracting company subject to approval. I think Mr. Schaub is mistaken in saying that "no account was taken of the horizontal displacement of the live load due to friction."

Referring to notes of calculations I find the following determination of required column sections:

A = Section of column in square inches.
M' = Bending moment from longitudinal thrust on one track in foot-pounds.
M'' = Bending moment from wind pressure.
r' = Radius of gyration in inches longitudinally.
r'' = Radius of gyration in inches transversely.

$N' = \frac{1}{2}$ thickness of post or distance from neutral axis to outer fiber, taken longitudinally.

$N'' =$ Same, taken transversely.

$L =$ Length of column in feet between fixed points.

$S =$ Strain per square inch from direct loading.

$S' =$ Strain per square inch on outer fiber from M'.

$S'' =$ Strain per square inch on outer fiber from M''.

By the specifications $s + s'$ shall not exceed 12 000,

and $s + s''$ " " "

Then longitudinal force on one track = distance between expansion joints × 600.

Displacement due to friction = longitudinal force × Ht. ÷ length of fixed span.

The lengths of the two columns were always practically equal, and as the force may act in either direction, the displacement is positive for every column.

Also—

$$M' = \tfrac{1}{2} \text{ longitudinal force} \times \frac{L}{2},$$

and

$$A = \frac{\text{Load} + \text{displacement}}{12\,000} + \frac{M' \times 12 \times N'}{12\,000 \times (r')^2}$$

a modification of above being made for posts not placed symmetrically.

For wind pressure we have—

$$\text{Displacement} = \frac{\text{Wind pressure} \times \text{Ht.}}{\text{Distance } c \text{ to } c \text{ of columns}},$$

$$M'' = \frac{\text{Wind pressure}}{2} \times \frac{L}{2},$$

and

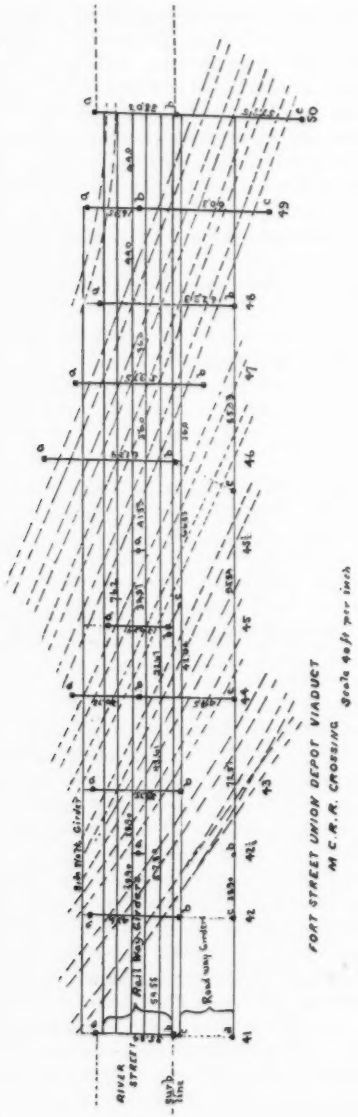
$$A = \frac{\text{Load} + \text{displacement}}{12\,000} + \frac{M'' \times 12 \times N''}{12\,000 \times (r'')^2},$$

then the greater value of A is taken as the least allowable section, that having been first approximately calculated to obtain r' and r''.

The following is a classification of the foundations, giving some information as to loads, etc.

There is also appended a sketch showing the arrangement of columns and girders at the crossing of the Michigan Central Railroad tracks. This portion was designed to provide for a roadway with inclined approaches on one side of the viaduct proper and a sidewalk on the other. The foundations for these columns were put in under the immediate supervision of the writer, but when he left in May, 1891, the roadway portion was not included in the bridge company's plans, and he is unable to say whether that was carried out or not.

There was in the alignment, besides some light curves, one 5° curve with easements at each end.


FORT STREET UNION DEPOT VIADUCT
M C.R.R. CROSSING
Scale 40 ft per inch
RIVER STREET
Rail Way Girders
Road way Girders

STATEMENT OF CLASSIFIED FOUNDATIONS.

Class. (See foundation plans.)	Greatest load in tons.	Size of stone cap.	Size of concrete base.	Number of piles.	Number of tons on each pile.	Tons allowable for 150 lbs. per square inch on concrete under stone cap.	Tons per square foot on earth under concrete.
A.....	97 at 84 *a*	3' x 3'	8' x 8'	.....	.....	97.2	1.51
B.....	159 " 72 *b*	3' 9" x 3' 9"	.....	9	17.7	151.9	
C.....	180 " 73 *b*	4' x 4'	.....	9	20.0	172.8	
D.....	212 " 50 *b*	4' 6" x 4' 6"	.....	13	16.3	218.7	
E.....	301½ " 49 *b*	5' 4" x 5' 4"	.....	16	18.85	307.2	
H.....	177½	3' 9" x 5' 0"	.....	12	14.8	202.5*	
G.....	151½ at 91 *a* and *b*	3' 9" x 3' 9"	10' x 10'	....	.....	151.9	1.51
K.....	184½	4' x4'	11' x 11'	.....	.....	172.8	1.52
Special for 41 *b*.	201	4' 0" x 5' 4"	.....	16	12 5	230.4*	
Special for 45 *a* and *b*..	226½	4' 6" x 4' 6"	.....	Notes not at hand.	.....	218.7	
Special for 46 *b*.....	320½	5' 4" x 6' 0"	.....	22	14.6	345.6*	
C special..	164½	4' 3" x 4' 3"	.....				
C special, 43 *a*.....	192	4' 6" x 4' 6"	.....	Notes not at hand.	.....	195.0 218.7	

*Designed to carry roadway column.

J. W. SCHAUB, M. Am. Soc. C. E.—The principles involved in the designs of a structure similar to this viaduct may be very simple, but the fact was brought out three years ago that there are very few structures of this kind which are properly designed. Previous to making the detail plans, the writer made an examination of some of the most important elevated structures in this country, especially in the East, and found the following salient features:

First.—Lack of proper provision against longitudinal force due to friction.

Second.—Imperfect connections at expansion joints.

Third.—Imperfect distribution of the pressure on the masonry. The writer now recalls one important structure where the bases of the columns were imbedded in the earth, owing to some slight changes in the grade of a street. Here the bases were of wrought iron, and the action of the rust had eaten away the metal so as to reduce the sections by about one-half, and in many cases the rivet heads were entirely eaten away. Again, it was found the rule, where anchorage was provided, to fix the ends of the columns, the connections for the anchor rods to columns were entirely inadequate to develop the strength of the rods. It occurred to the writer at that time that a suitable base for a column was a casting high enough to keep the end of the column away from the ground. The casting had advantages which were twofold. It was better able to withstand the action of the rust, because

the sections would be made heavier than in any form of wrought base. Again, it can be so designed as to distribute the pressure over the masonry much more effectively and much cheaper than by any other means. Mr. Moore is mistaken in regard to the computations. This viaduct was designed, and all of the computations were made, either by the writer himself or by his assistant, Mr. F. C. McMath, and no account was taken of the horizontal displacement due to friction.